NASA/CR-97- 205862

Semi-Annual Report:

Analysis of Solar Spectral Irradiance Measurements from the SBUV/2-Series and the SSBUV Instruments

Period of Performance: 1 March 1997 to 31 August 1997

2 October 1997

Contract Number:	NASW-4864
Principal Investigator:	Richard P. Cebula
Co-Investigators:	Matthew T. DeLand Ernest Hilsenrath

1. SUMMARY OF ACTIVITY DURING CURRENT PERFORMANCE PERIOD

1.1 Validation of the Long-term NOAA-11 SBUV/2 Solar Irradiance Data Set

During this period of performance, 1 March 1997 – 31 August 1997, the NOAA-11 SBUV/2 solar spectral irradiance data set was validated using both internal and external assessments. Initial quality checking revealed minor problems with the data (*e.g.* residual goniometric errors, that were manifest as differences between the two scans acquired each day). The sources of these errors were determined and the errors were corrected. Time series were constructed for selected wavelengths and the solar irradiance changes measured by the instrument were compared to a Mg II proxy-based model of short- and long-term solar irradiance variations. This analysis suggested that errors due to residual, uncorrected long-term instrument drift have been reduced to less than 1-2% over the entire 5.5 year NOAA-11 data record. Detailed statistical analysis was performed. This analysis, which will be documented in a manuscript now in preparation, conclusively demonstrates the evolution of solar rotation periodicity and strength during solar cycle 22.

1.2 Comparisons with Other Instruments

Comparisons between the NOAA-11 SBUV/2 solar irradiance data and data from the UARS SOLSTICE (Versions 8 and 9) and UARS SUSIM (Versions 18 and 19) instruments were performed during this performance period as part of the validation of the NOAA-11 data. These comparisons demonstrate that the precision and long-term accuracy of the NOAA-11 SBUV/2 data equals that of Version 19 SUSIM data set and exceeds that of the Version 9 SOLSTICE data set. This work will be documented in a forthcoming manuscript.

1.3 NOAA-9 SBUV/2 Activities

We have continued a low-level effort of tracking the solar data taken by the SBUV/2 instrument onboard the NOAA-9 spacecraft. In May 1997 the performance of the instrument's grating drive system degraded significantly, and the drive became stuck in the spectral scan mode on May 6. Although the Spacecraft Operations Control Center (SOCC) was able to free the drive mechanism (permitting the resumption of normal ozone measurements), all spectral scan operations (including daily solar measurements) were discontinued. Daily solar Mg II measurements have continued and solar measurements at the twelve ozone channels, previously acquired once a week, are now also being taken daily.

Due to resource demands and scheduling conflicts at NOAA's SOCC, the NOAA-9 SBUV/2 instrument was taken out of active duty on 14 July 1997. No instrument-specific commands, including commands necessary to continue the daily Mg II observations were to be sent, and only approximately 1-2 orbits of nadir viewing data were being acquired each day. An international letter

writing campaign was mounted to demonstrate the importance of the SBUV/2 solar observations to NOAA (the data are used by more than 65 scientists from at least a dozen countries). We are happy to report that this effort was successful and that daily NOAA-9 SBUV/2 Mg II measurements resumed on 5 August 1997. This instrument continues to operate as of 1 October 1997, and has now compiled an unprecedented 12-year record of solar UV spectral irradiance data. Sensor aging related increases in the noise level of the NOAA-9 SBUV/ Mg II data were noted. However, comparisons with concurrent Mg II data from the SUSIM instrument indicate that the NOAA-9 data remain quite usable. If further support becomes available, we hope to apply the techniques we have developed for correcting long-term instrument sensitivity changes to the NOAA-9 SBUV/2 irradiance data set.

1.4 Data Release

The NOAA-9 and NOAA-11 discrete Mg II data were released to the user community via an anonymous ftp site. A notice in the June 1997 issue of *SolarNews* announced the availability of these data. A data set containing 5 nm averages of the solar spectral irradiances measured by SSBUV on each of its eight Space Shuttle missions was also made available to the use community via this ftp site.

```
ftp         ssbuv.gsfc.nasa.gov
login:      anonymous
password:   your E-mail address

cd pub/solar/sbuv2/noaa9      (for NOAA-9 data)
cd pub/solar/sbuv2/noaa11     (for NOAA-11 data)
cd pub/solar/ssbuv            (for SSBUV data)
```

1.5 Presentations and Publications

During this period of performance we have been working to finalize two papers that document the core of this research effort – the creation of the NOAA-11 SBUV/2 spectral scan irradiance data set and validation and scientific analysis of these data. Those manuscripts are essentially complete and will be submitted shortly.

A paper discussing extensive, initial comparisons of the NOAA-11 irradiances with the SOLSTICE (Version 8) and the SUSIM (Version 18) data was presented at the Spring 1997 AGU Meeting in Baltimore, MD. A copy of that paper is attached. Two papers discussing recent results were submitted for presentation at the Fall 1997 AGU Meeting in San Francisco, CA.

In response to referee's comments, a paper describing initial GOME solar irradiance analysis results, presented at the SOLERS22 Workshop in Sunspot, NM in June 1996, was twice revised. This paper was recently accepted for publication by *Solar Physics*. A preprint of this "in press" paper is

attached. This paper and two additional papers discussing analysis of SBUV/2 Mg II data (preprints of those papers were included in the last Semi-annual Report) are scheduled for publication in the January 1998 issue of *Solar Physics.*

Finally, in a closely related activity, Mr. DeLand participated in the 2nd IAGA/ICMA workshop "Solar Activity Effects on the Middle Atmosphere" in Prague, Czech Republic. During this trip, which was supported under a separate contract, Mr. DeLand presented the paper "SSBUV and NOAA-11 SBUV/2 Solar Variability Measurements". A copy of that presentation is attached. The full paper is in preparation for submission to *Studia Geophysica et Geodaetica.*

Cebula, R. P., and M. T. DeLand, "Influence of Short-Term Solar Spectral UV Variability on the Determination of Solar Cycle Minimum", EOS Trans. Amer. Geophys. Union, 78(17) , Fall Meet. Suppl., submitted, 1997.

DeLand, M. T., and R. P. Cebula, "Identification of Solar Cycle 23 minimum from Solar UV Measurements: NOAA-9 and NOAA-11 SBUV/2, UARS SUSIM, and UARS SOLSTICE", EOS Trans. Amer. Geophys. Union, 78(17), Fall Meet. Suppl., submitted, 1997.

DeLand, M. T., and R. P. Cebula, "SBUV/2 Long-Term Measurements of Solar Spectral Variability", EOS Trans. Amer. Geophys. Union, 78(17) , Spring Meet. Suppl., S58, 1997.

DeLand, M. T., R. P. Cebula, and E. Hilsenrath, "SSBUV and NOAA-11 SBUV/2 Solar Variability Measurements," 2nd IAGA/ICMA workshop "Solar Activity Effects on the Middle Atmosphere, Prague, Czech Republic, 18-22 August 1997.

Weber, M., J. P. Burrows, and R. P. Cebula, "GOME Solar UV/VIS Irradiance Measurements in 1995 and 1996 - First Results on Proxy Solar Activity Studies", *Solar Physics*, in press, 1997.

2. WORK PLANNED: 1 SEPTEMBER 1997 – 28 FEBRUARY 1998

During the next period of performance 1 September 1997 through 28 February 1998, the following activities are planned:

The manuscript describing the creation of corrected NOAA-11 solar irradiance data set will be finalized and submitted to the *Journal of Geophysical Research.*

We will complete the extensive statistical analysis of the NOAA-11 solar irradiance data. These results will be compared to results from similar analyses of SOLSTICE and SUSIM data during the period in which all three instruments were operating simultaneously (September 1991 - October 1994). A manuscript describing the complete results will be finalized and submitted to the *Journal of Geophysical Research.*

A NOAA-11 SBUV/2 1 nm averaged solar irradiance data set will be created and archived on the SSBUV workstation for anonymous ftp and Internet access. A SBUV/2–SSBUV solar irradiance Website will be created. The availability of these data and the existence of the Website will be announced to the solar physics community via the *SolarNews* monthly newsletter and the American Geophysical Union's SPA Section newsletter.

We will continue low level monitoring and analysis of the Mg II data from the NOAA-9 SBUV/2 instrument.

Influence of Short-Term Solar Spectral UV Variability on the Determination of Solar Cycle Minimum

R P Cebula and M T DeLand (Hughes STX Corporation, Lanham, MD 20706; tel. 301-794-5265; *cebula@ssbuv.gsfc.nasa.gov*)

Determining the precise date for solar activity minimum on solar cycle time scales requires an understanding of potential sources of variability on shorter time scales. Direct use of daily measurements is subject to the effects of both observational noise and rotational modulation. Uncertainties of 0.5% or less are significant when evaluating a solar cycle dynamic range of 8-9% – that observed for the 205 nm irradiance and the Mg II index. Simple smoothing functions such as running averages are commonly used to minimize or remove the effects of short-term variations. Statistical analysis shows that the Mg II index's nominal 27-day rotational modulation period varied between 26 and 29 days during Cycle 22, which can allow some variability to remain after using a single-period (*e.g.* 27-day) smoothing function.

Solar variability on intermediate time scales (*e.g.* 50-250 days), which has been observed previously in sunspot numbers, could also influence the identification of solar minimum. We used periodogram analysis to examine the NOAA-11 SBUV/2, UARS SUSIM (V19), and UARS SOLSTICE (V09) spectral irradiance and Mg II data sets, and found no evidence of intermediate-term periodicities related to solar activity. Occasional instances of periodogram power were not repeatable between instruments in either period or spectral location, suggesting that they may represent artifacts.

Our results suggest that the use of daily unsmoothed values to identify solar cycle extrema in date and magnitude is problematic because of the impact of rotational modulation and measurement noise. Running averages which smooth the data on rotational time scales provide significant improvement, although the evolution of rotational activity during a solar cycle suggests that averaging windows of 35 days or more are most effective. We find no evidence for periodic behavior on intermediate time scales (during Cycle 22) which would influence the identification of solar minimum.

1. 1997 Fall Meeting
2. 00650983
3. (a) Richard P. Cebula
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4. SH
5. (a) SH03 Solar Cycle 23: When Was the Minimum, and What are the Future Implications?

   (b) 7549 Ultraviolet emissions
   7536 Solar activity cycle
   1650 Solar variability
6. Poster preferred
7. none
8.
9. C
10. Willing to chair session on middle atmosphere or solar activity.
11. No

Identification of Solar Cycle 23 Minimum from Solar UV Measurements: NOAA-9 and NOAA-11 SBUV/2, UARS SUSIM, UARS SOLSTICE

M T DeLand and R P Cebula (Hughes STX Corporation, Lanham, MD 20706; tel. 301-794-5254; *mdeland@ccmail.stx.com*)

During solar cycle 22, solar spectral UV data sets of more than 5 years in length have been produced by four instruments. The NOAA-9 and NOAA-11 SBUV/2 instruments acquired solar spectral data from March 1985 to present and December 1988 to October 1994, respectively. The UARS SUSIM V19 irradiance data set covers October 1991 to September 1996. The UARS SOLSTICE V9 irradiance data set covers October 1991 to December 1996.

The SUSIM V19 and SOLSTICE V9 irradiance data sets are now of sufficient length to permit an assessment of the date at which solar activity reached a minimum between cycles 22 and 23. The NOAA-11 data set provides validation of the UARS data, but does not cover the solar minimum period. Shortward of 290 nm, where solar cycle variability is 2% or more, we find that the identification of solar minimum depends significantly on the instrument and wavelength band chosen. For example, the SUSIM data averaged over 240-250 nm and smoothed with a 27-day running average have their minimum value on 28 April 1996, while the average irradiance over 200-208 nm (*shortward of the Al edge*) reaches a minimum on 26 April 1996. Using these same wavelength bands, the SOLSTICE data give solar minimum dates of 4 May and 29 December 1996 respectively. In each case, there are many other dates whose absolute values are equal to within a small measurement error. We use a solar activity model based on the NOAA-11 Mg II index to show that medium and long-term calibration changes play an important role in the determination of solar minimum from irradiance data.

SUSIM, SOLSTICE, and NOAA-9 SBUV/2 also produce Mg II index data, which are inherently less sensitive to calibration errors. The NOAA-9 Mg II index data cover the minima of both Cycle 22 and 23, and indicate ≤0.5% difference between the absolute levels at those times. The dates for the minimum of solar cycle 23 in 27-day smoothed Mg II index data for NOAA-9, SUSIM, and SOLSTICE are 12 April, 22 April, and 27 April 1996 respectively. These dates

1. 1997 Fall Meeting
2. 005328042
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   (d) *mdeland@ccmail.stx.com*
4. SH
5. (a) SH03 Solar Cycle 23: When Was the Minimum, and What are the Future Implications?

   (b) 7549 Ultraviolet emissions
   7536 Solar activity cycle
   1650 Solar variability
6. Oral preferred
7. 20%; 1997 ICMA Workshop
8.
9. C
10. Willing to chair session on middle atmosphere or solar activity.
11. No

are more self-consistent than the irradiance data, although once again there are many values within a few tenths of a percent of the minimum value listed here. Because of the challenges associated with correcting irradiance data to better than 1% accuracy, we recommend the use of proxy indexes for the identification of solar cycle extreme dates.

SBUV/2 Long-Term Measurements of Solar Spectral Variability

Matthew T. DeLand, Richard P. Cebula

Hughes STX Corporation
Greenbelt, MD

presented at the 1997 Spring American Geophysical Union Meeting,

Baltimore, MD

30 May 1997

supported by NASA Grant NASW-4864

The NOAA-11 SBUV/2 spectral solar data have been corrected for long-term instrument changes to produce a 5.5 year data record during solar cycle 22 (December 1988 - October 1994). Residual drifts in the data at long wavelengths are ±1% or less. At 200-205 nm, where solar variations drive stratospheric photochemistry, these data indicate long-term solar changes of 5-7% from the maximum of Cycle 22 in April 1991 through the end of the NOAA-11 data record. Comparisons of NOAA-11 data with UARS SUSIM and SOLSTICE for the period October 1991 - October 1994, when all 3 instruments were operating simultaneously, show that the observed long-term variations in 200-205 nm irradiance agree to within 2%. This result is consistent with predictions from the Mg II proxy index.

The SBUV/2 instruments represent a valuable resource for long-term solar UV activity studies because of their overlapping data records. In addition to the NOAA-11 data presented here, the NOAA-9 SBUV/2 instrument began taking data in March 1985 and is still operating, providing a complete record of Cycle 22 behavior from a single instrument. Three additional SBUV/2 instruments are scheduled to be launched between 1997 and 2003, which should permit full coverage of solar cycle 23.

- Daily measurements made over 160-405 nm wavelength region from December 1988 to October 1994

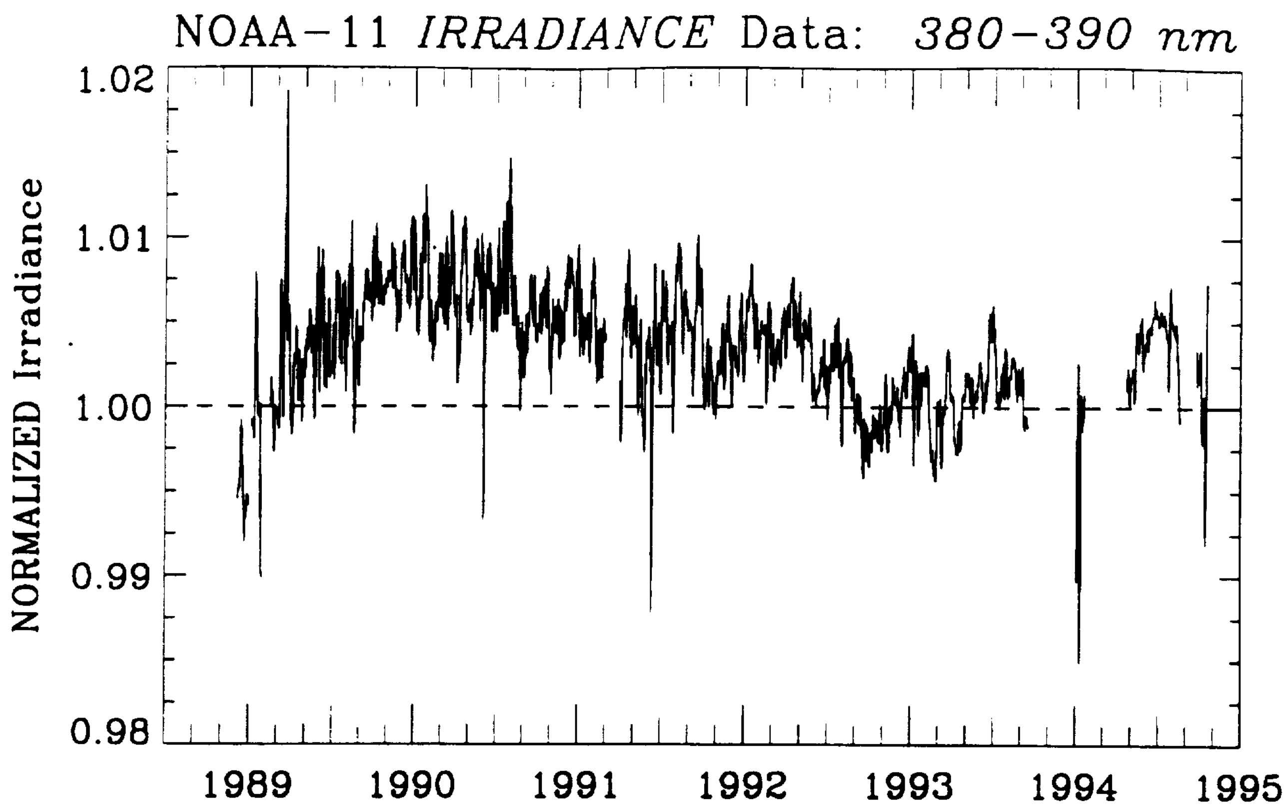
- On-board calibration system corrects for diffuser reflectivity change only

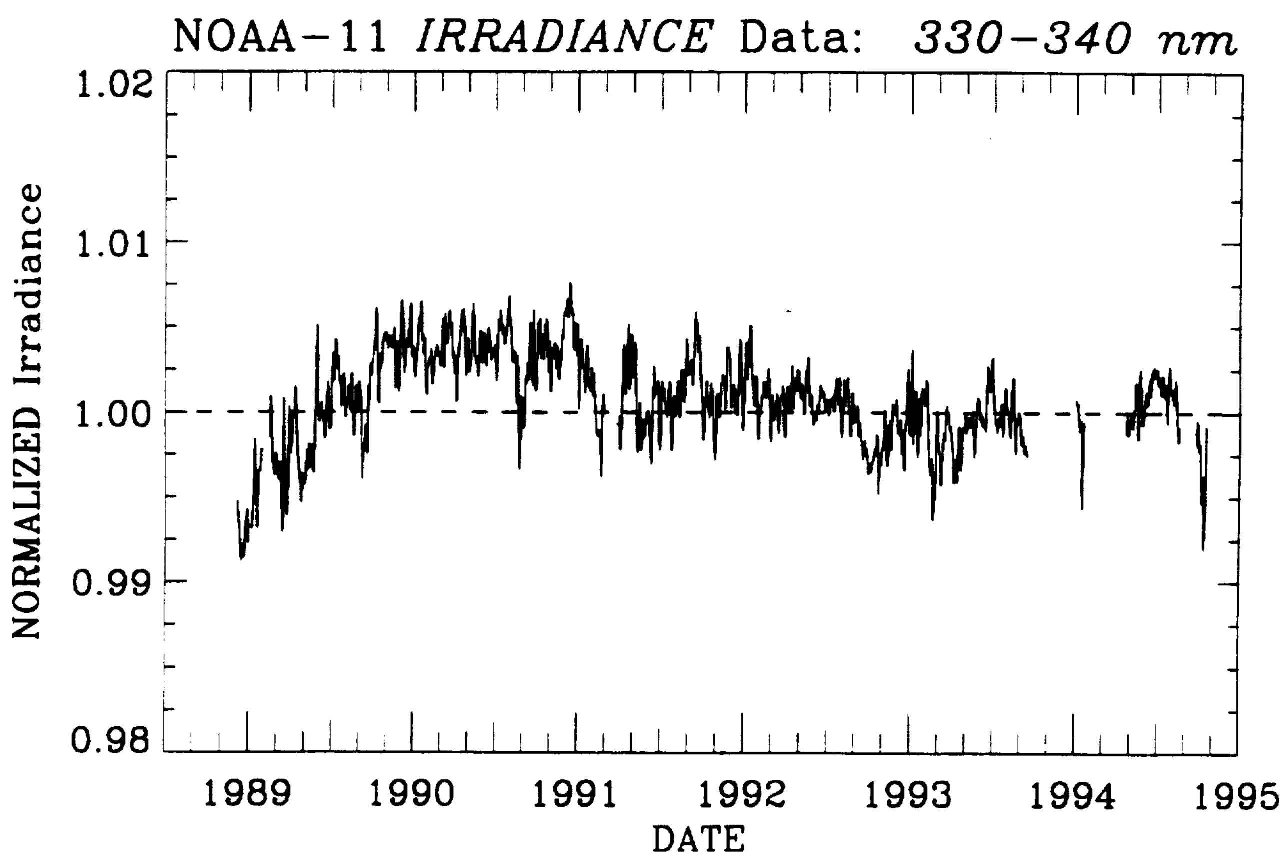
- Coincident observations with SSBUV flights used to characterize long-term instrument throughput changes as functions of time, wavelength

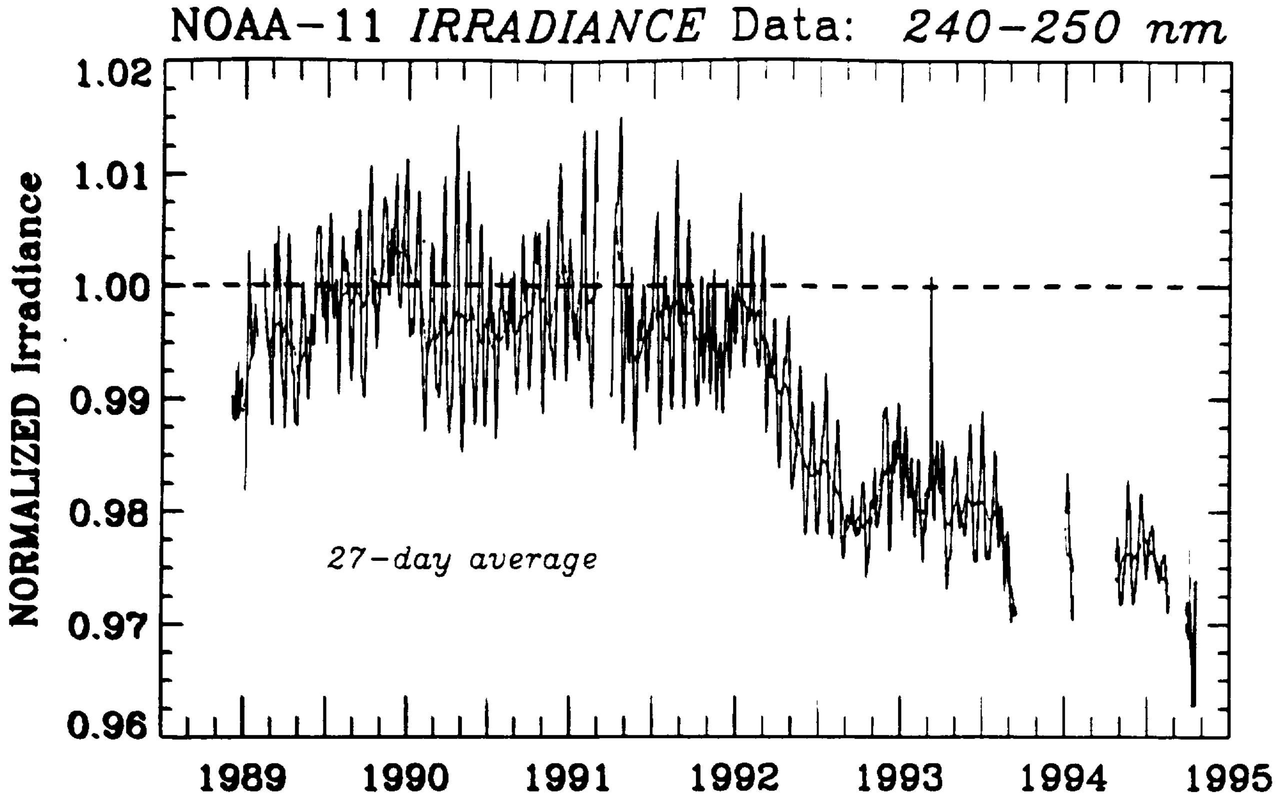
- NOAA-11 irradiance data show long-term drift $\leq$ 1% for $\lambda > 300$ nm; This is consistent with expectation of little/no solar activity, indicates accuracy of corrections

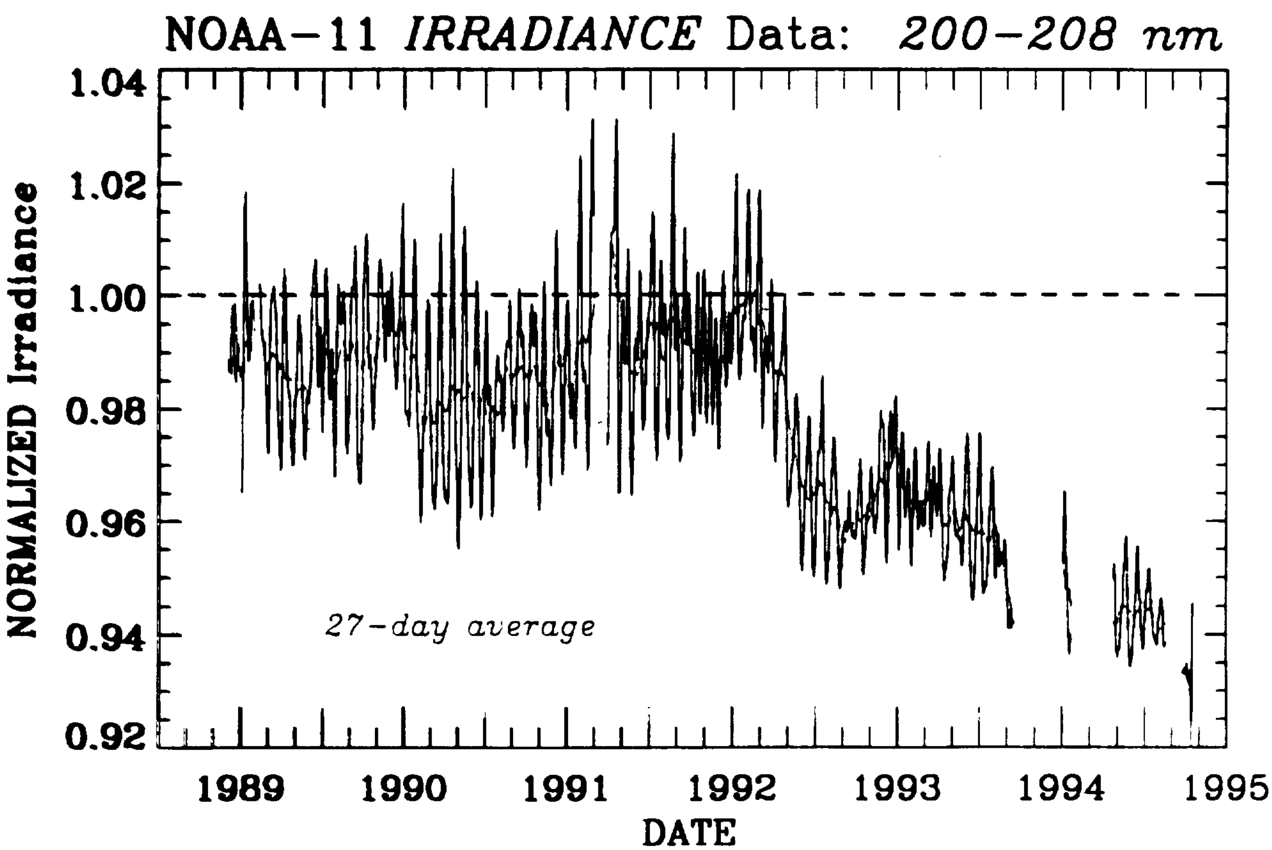
- Shorter wavelengths show regular rotational modulation (up to 5-6% at 200-208 nm, 2-3% at 240-250 nm) during maximum and decline of Cycle 22; Periods of 13-day variability in Fall 1991, late 1992 also present

NOAA-11 Solar Irradiance Results


NOAA-11 *IRRADIANCE* Data: *380-390 nm*
NORMALIZED Irradiance
1.02
1.01
1.00
0.99
0.98
1989
1990
1991
1992
1993
1994
1995

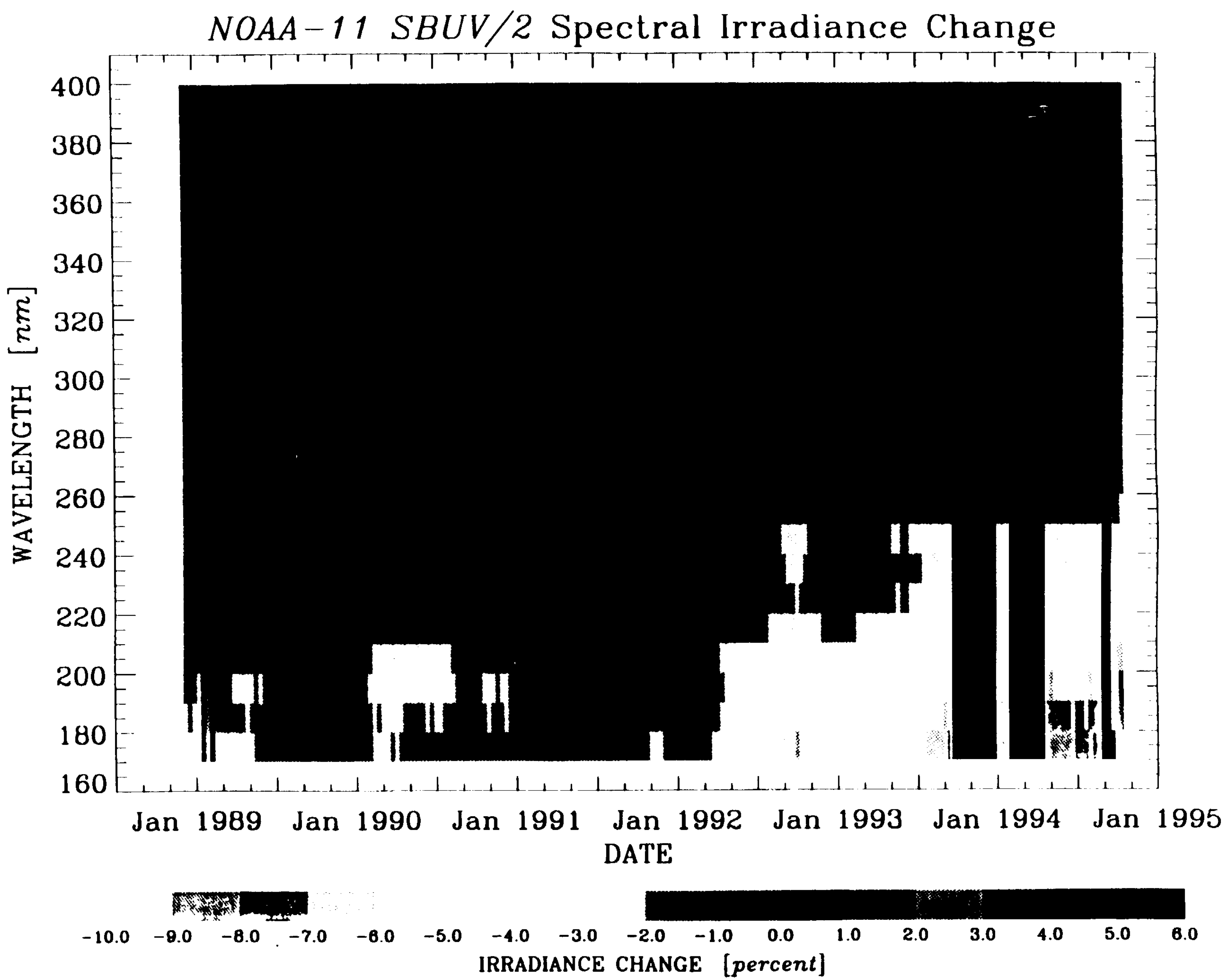

NOAA-11 *IRRADIANCE* Data: *330-340 nm*
NORMALIZED Irradiance
1.02
1.01
1.00
0.99
0.98
1989
1990
1991
1992
1993
1994
1995
DATE


NOAA-11 IRRADIANCE Data: 240-250 nm
NORMALIZED Irradiance
1.02
1.01
1.00
0.99
0.98
0.97
0.96
27-day average
1989
1990
1991
1992
1993
1994
1995


NOAA-11 IRRADIANCE Data: 200-208 nm
NORMALIZED Irradiance
1.04
1.02
1.00
0.98
0.96
0.94
0.92
27-day average
1989
1990
1991
1992
1993
1994
1995
DATE

- Plot of all data in 10 nm bands (81-day average) shows $\Delta F < \pm 1\%$ [*darker green*] for $\lambda > 270$ nm, more long-term change shortward of Mg edge at 210-250 nm [*lighter green*], largest change below Al edge at $\lambda < 210$ nm [*yellow, orange*]; End of Cycle 22 maximum in Spring 1992 visible at $\lambda < 270$ nm

- Long-term changes at short wavelengths determined from smoothed data are approximately 6% at 200-208 nm, 3-3.5% at 240-250 nm; *How can we evaluate instrument drift at these wavelengths?*

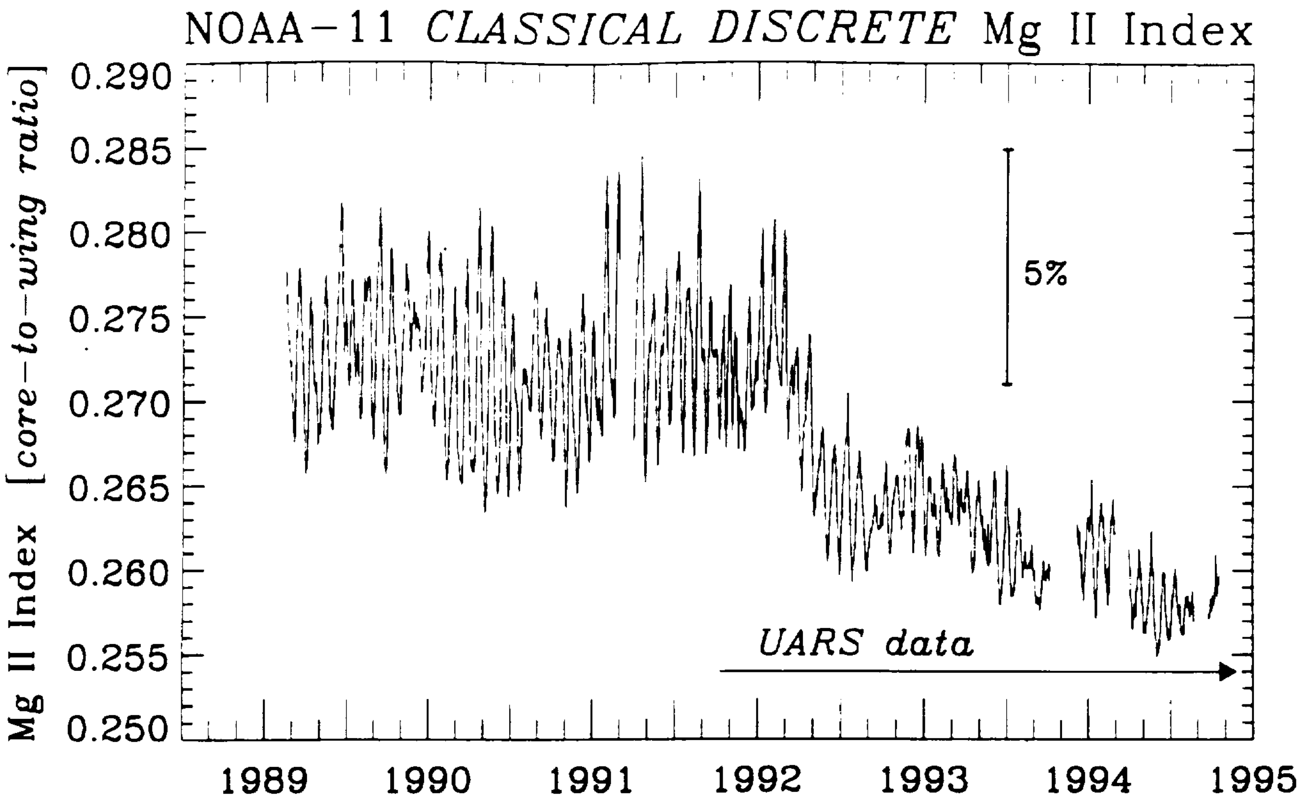


NOAA-11 SBUV/2 Spectral Irradiance Change
WAVELENGTH [nm]
400
380
360
340
320
300
280
260
240
220
200
180
160
Jan 1989
Jan 1990
Jan 1991
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
IRRADIANCE CHANGE [percent]

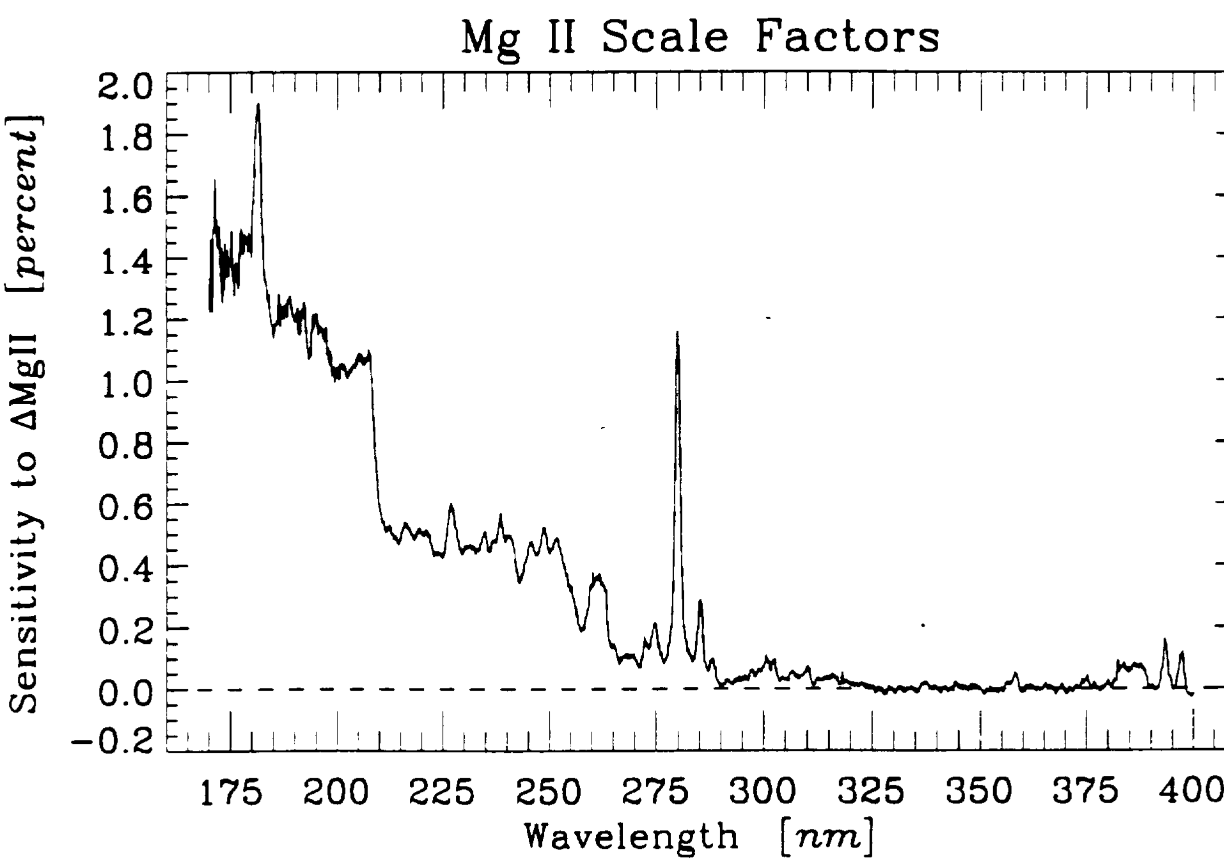
- Solar irradiance variations modeled using NOAA-11 Mg II index, scale factors; NOAA-11 Mg II agrees with NOAA-9 Mg II, SUSIM Mg II to within 1% during overlap periods

- "Desolarized" NOAA-11 irradiance data has long-term drift of +2% at 200-208 nm, < 1% at 240-250 nm.

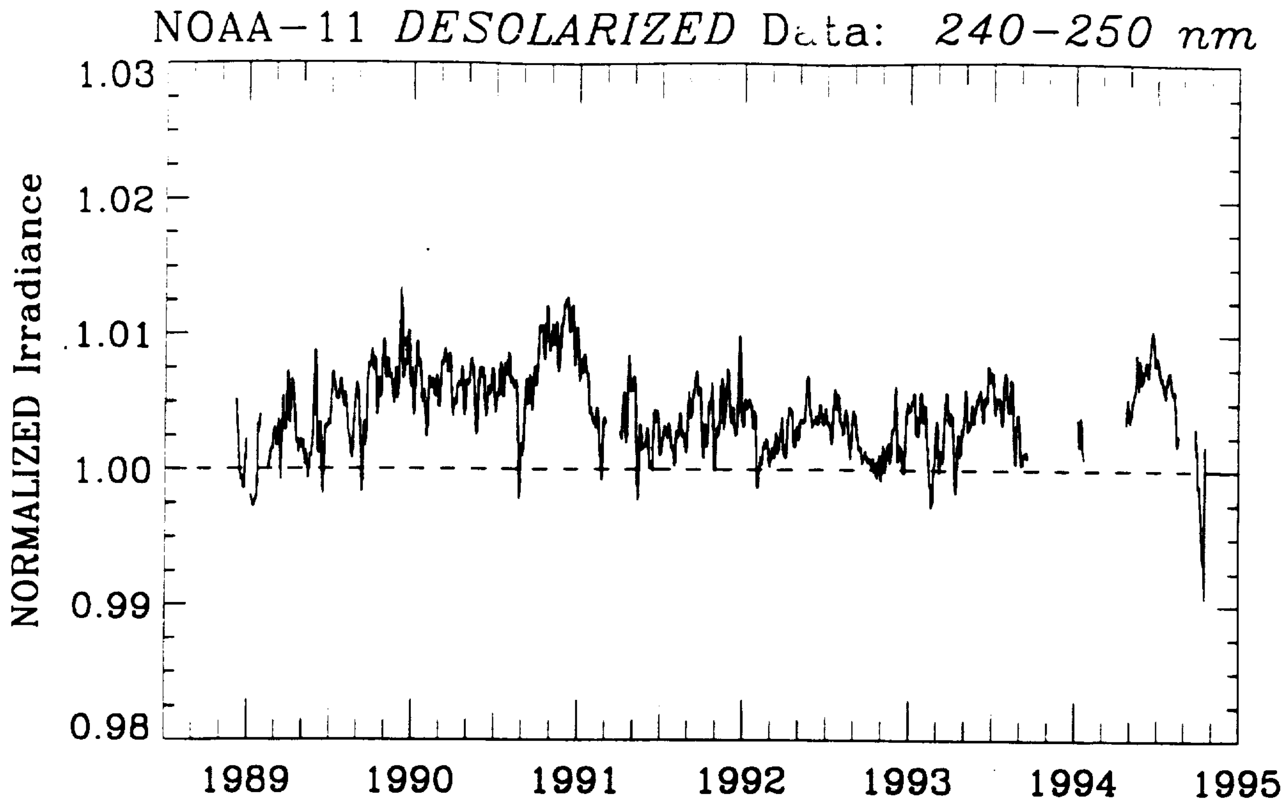
- If (Mg II + scale factor) result is correct for long-term change, $\Delta F_{solar} \approx -(6\text{-}7)\%$ at 200-208 nm, –(3-4)% at 240-250 nm during 1989-1994; *Compare with other instruments for validation*

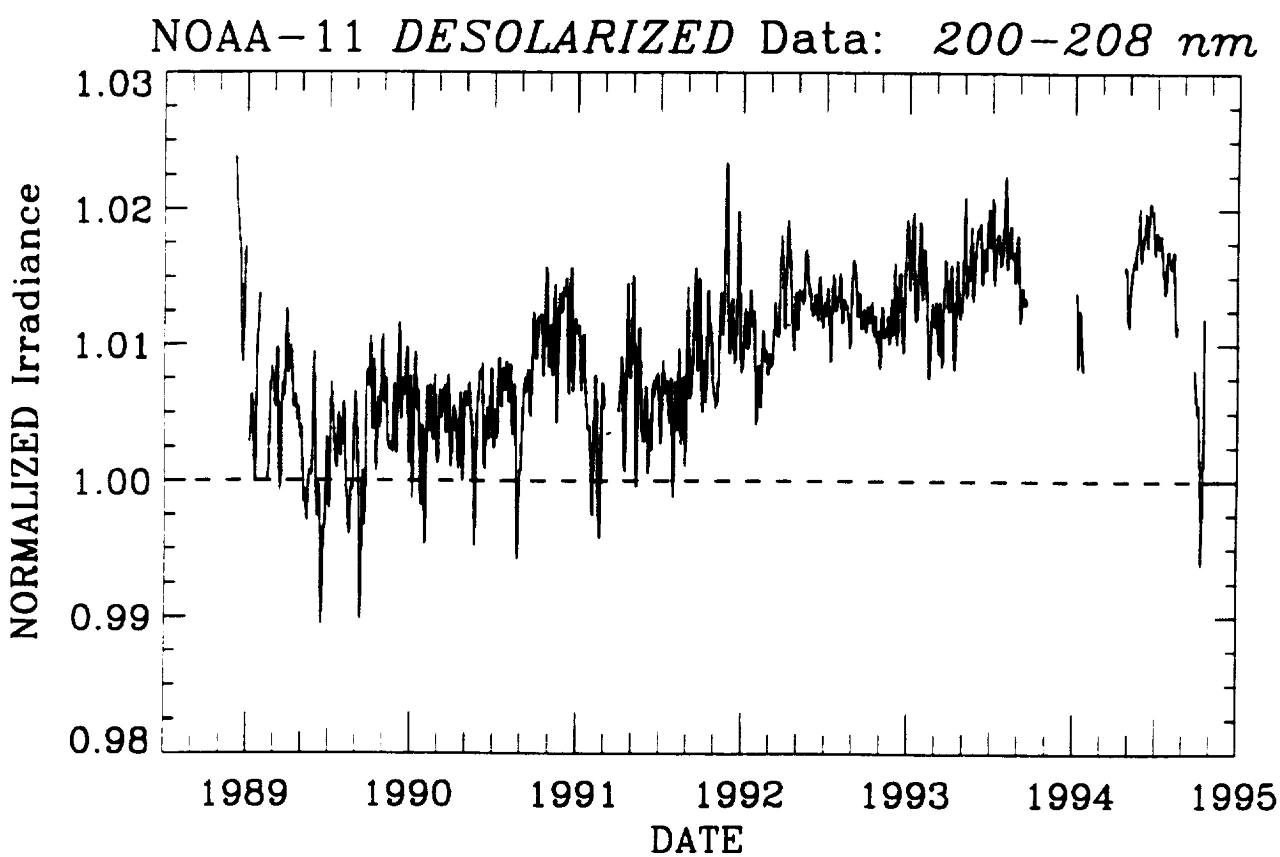


NOAA-11 CLASSICAL DISCRETE Mg II Index
Mg II Index [core-to-wing ratio]
0.290
0.285
0.280
0.275
0.270
0.265
0.260
0.255
0.250
5%
UARS data
1989
1990
1991
1992
1993
1994
1995



Mg II Scale Factors
Sensitivity to ΔMgII [percent]
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
175
200
225
250
275
300
325
350
375
400
Wavelength [nm]


NOAA-11 *DESOLARIZED* Data: *240-250 nm*
NORMALIZED Irradiance
1.03
1.02
1.01
1.00
0.99
0.98
1989
1990
1991
1992
1993
1994
1995

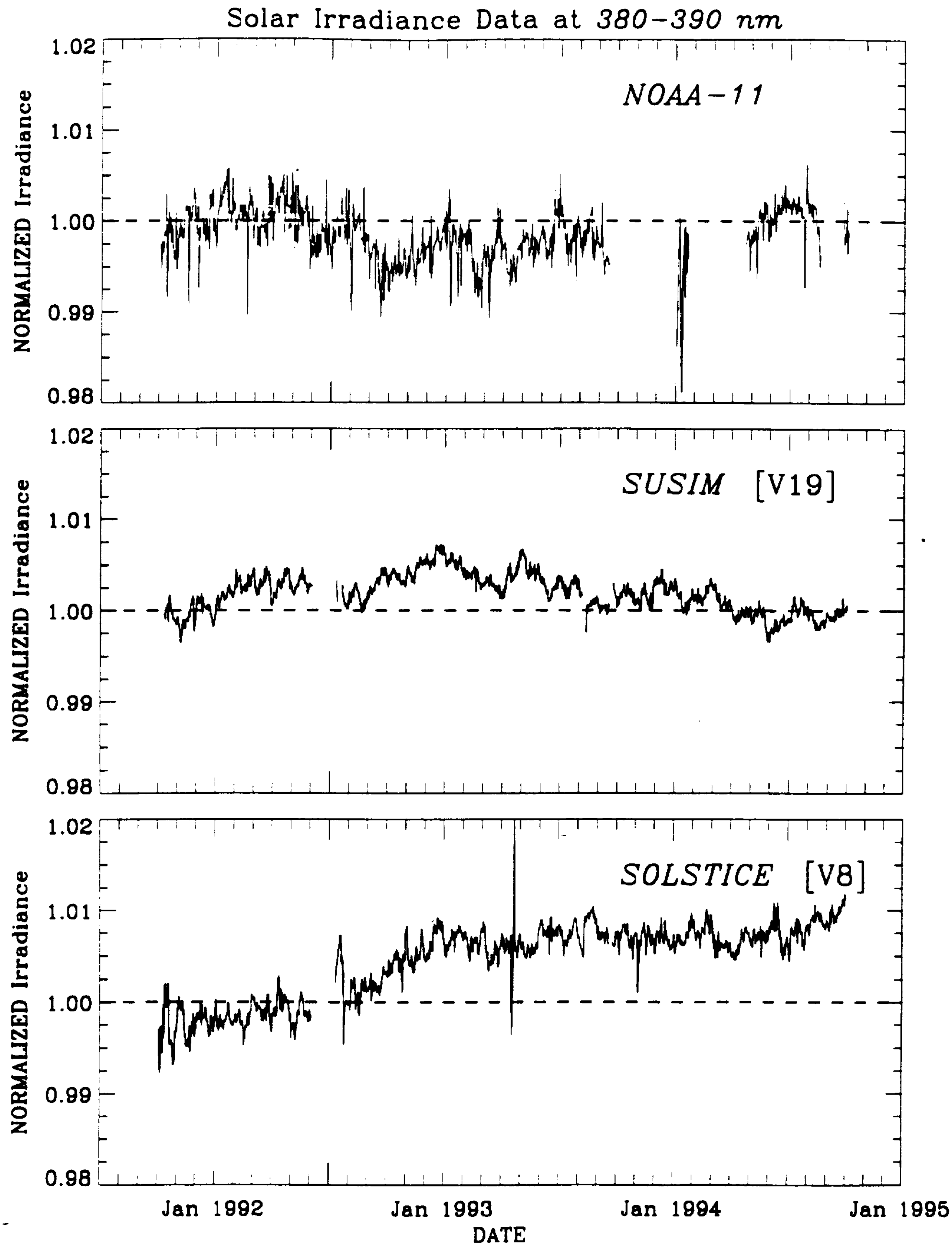

NOAA-11 *DESOLARIZED* Data: *200-208 nm*
NORMALIZED Irradiance
1.03
1.02
1.01
1.00
0.99
0.98
1989
1990
1991
1992
1993
1994
1995
DATE

- NOAA-11 data overlap UARS solar instruments (SUSIM, SOLSTICE) during Oct 1991 - Oct 1994; Results shown here use SUSIM V19 data, SOLSTICE V8 data

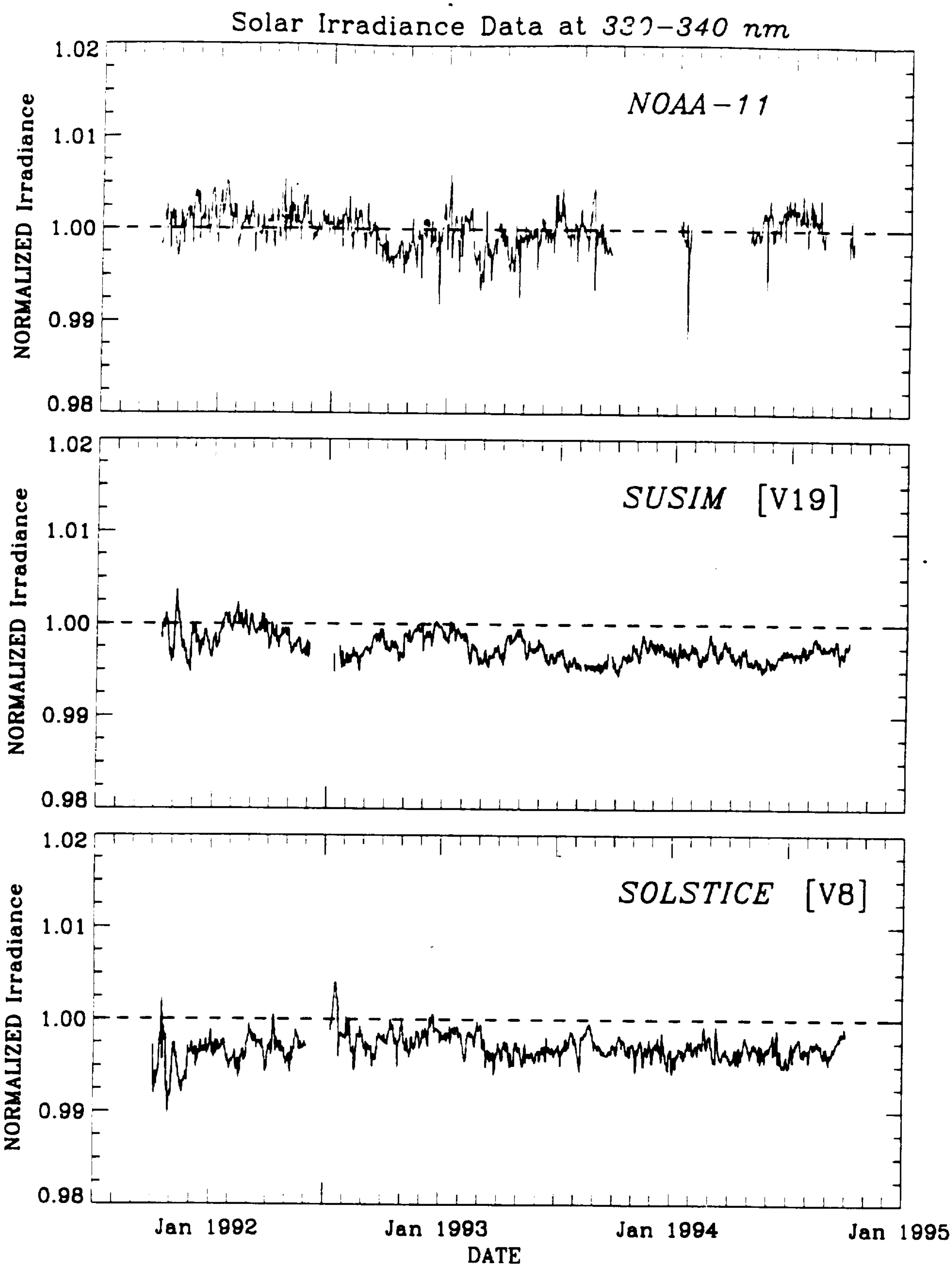
- Long wavelengths (λ > 300 nm) generally have ΔF < ±1%; Raw data at short wavelengths (λ < 260 nm) show similar rotational activity, long-term decrease

- Evaluate drift at short wavelengths by removing predicted solar change from all data; Results good to 1-2% for selected bands; No indication of long-term bias in Mg II-based solar change values

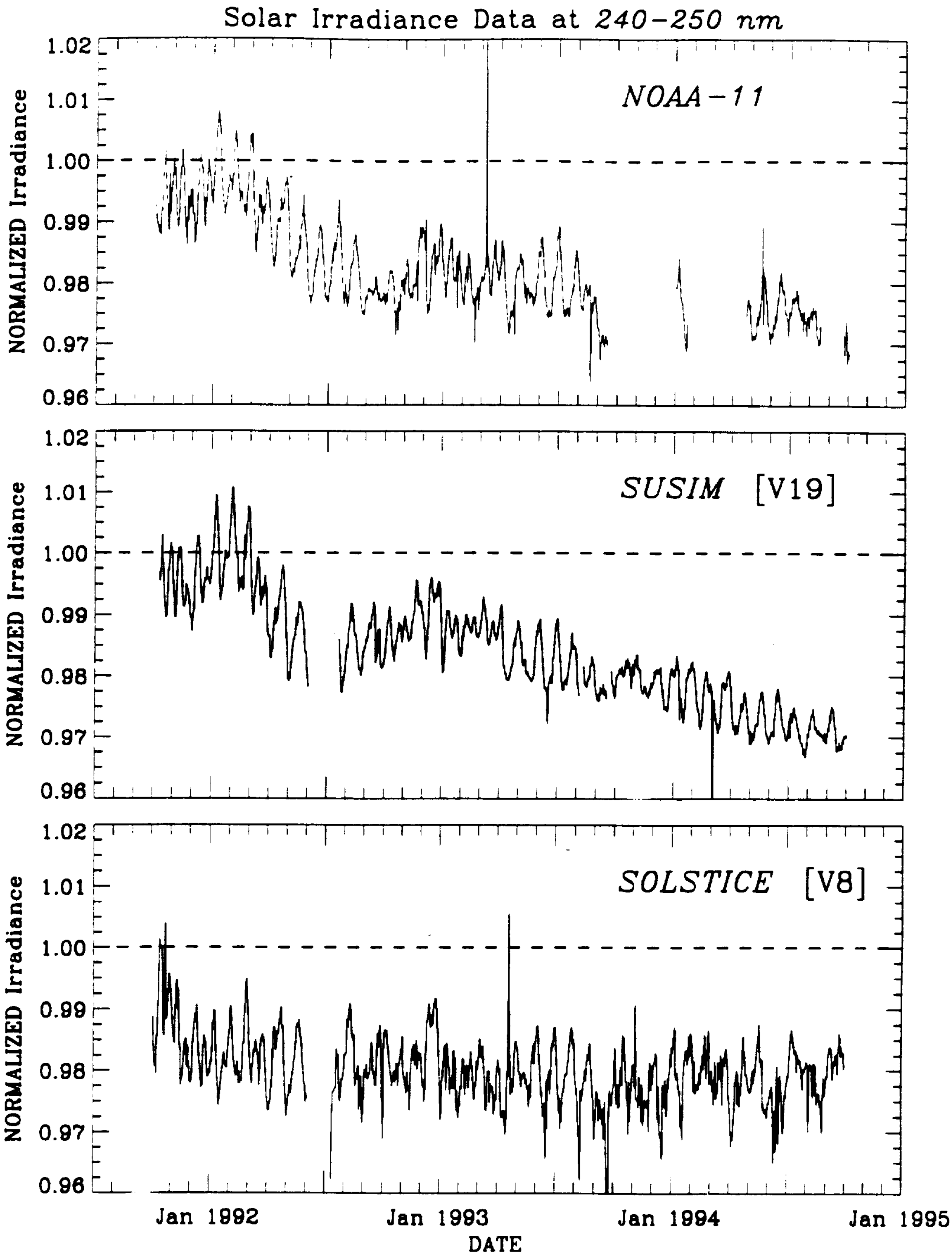
Comparisons with UARS Irradiances

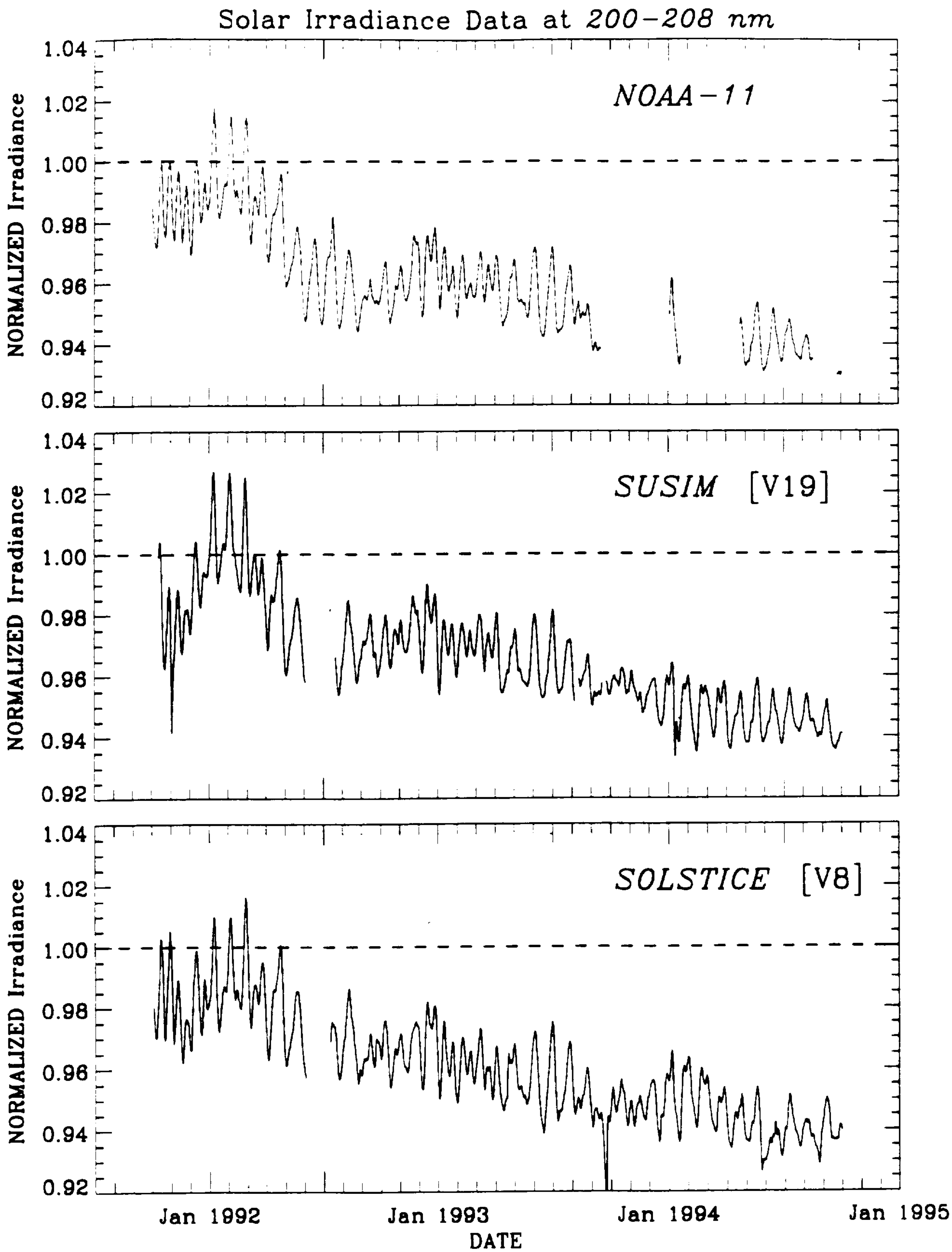


Solar Irradiance Data at 380–390 nm
NOAA–11
SUSIM [V19]
SOLSTICE [V8]
NORMALIZED Irradiance
1.02
1.01
1.00
0.99
0.98
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE

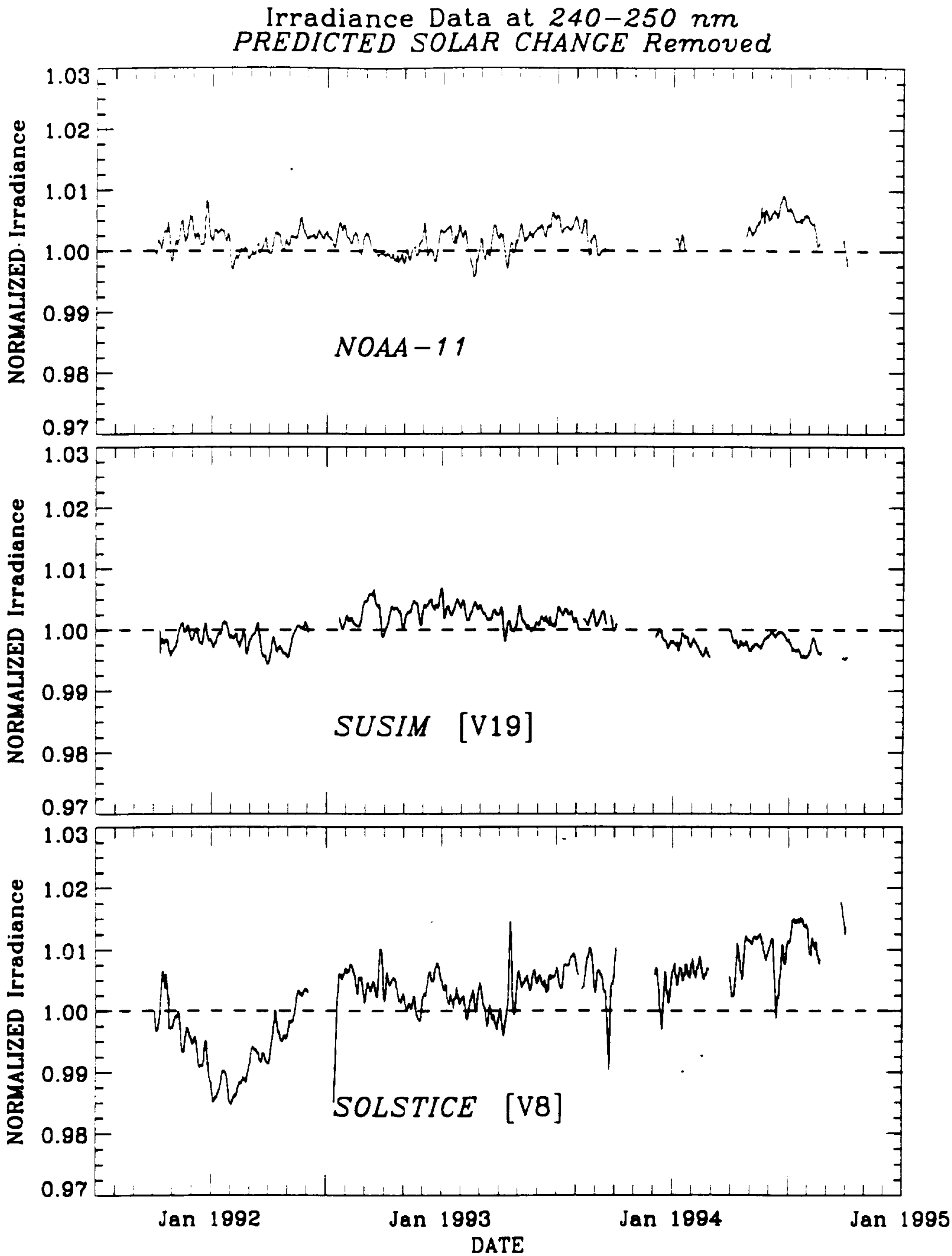


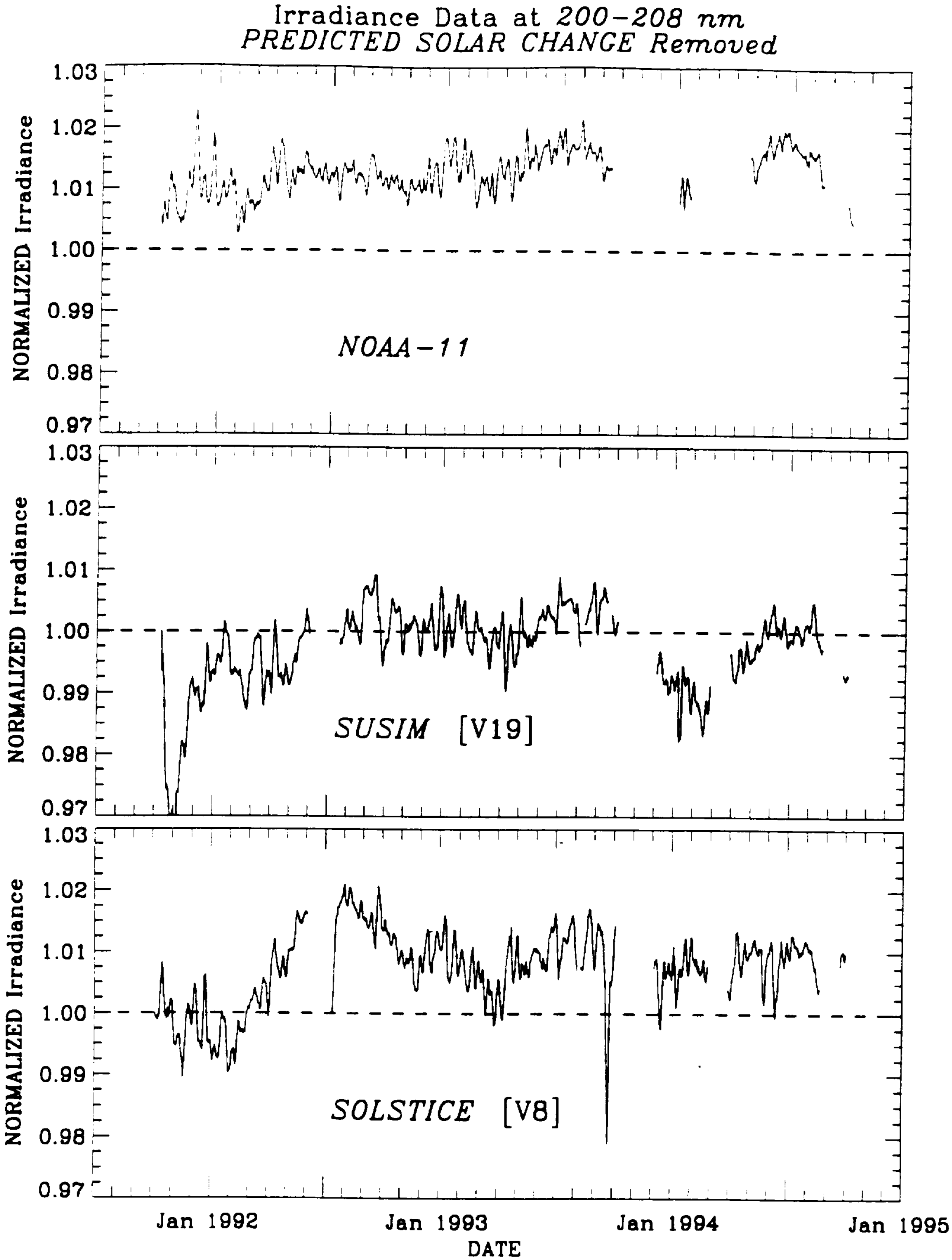
Solar Irradiance Data at 330-340 nm
NOAA-11
SUSIM [V19]
SOLSTICE [V8]
NORMALIZED Irradiance
1.02
1.01
1.00
0.99
0.98
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE


Solar Irradiance Data at 240–250 nm
NOAA–11
SUSIM [V19]
SOLSTICE [V8]
NORMALIZED Irradiance
1.02
1.01
1.00
0.99
0.98
0.97
0.96
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE



Solar Irradiance Data at 200–208 nm
NOAA–11
SUSIM [V19]
SOLSTICE [V8]
NORMALIZED Irradiance
1.04
1.02
1.00
0.98
0.96
0.94
0.92
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE


Irradiance Data at 240–250 nm
PREDICTED SOLAR CHANGE Removed
NORMALIZED Irradiance
1.03
1.02
1.01
1.00
0.99
0.98
0.97
NOAA–11
SUSIM [V19]
SOLSTICE [V8]
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE



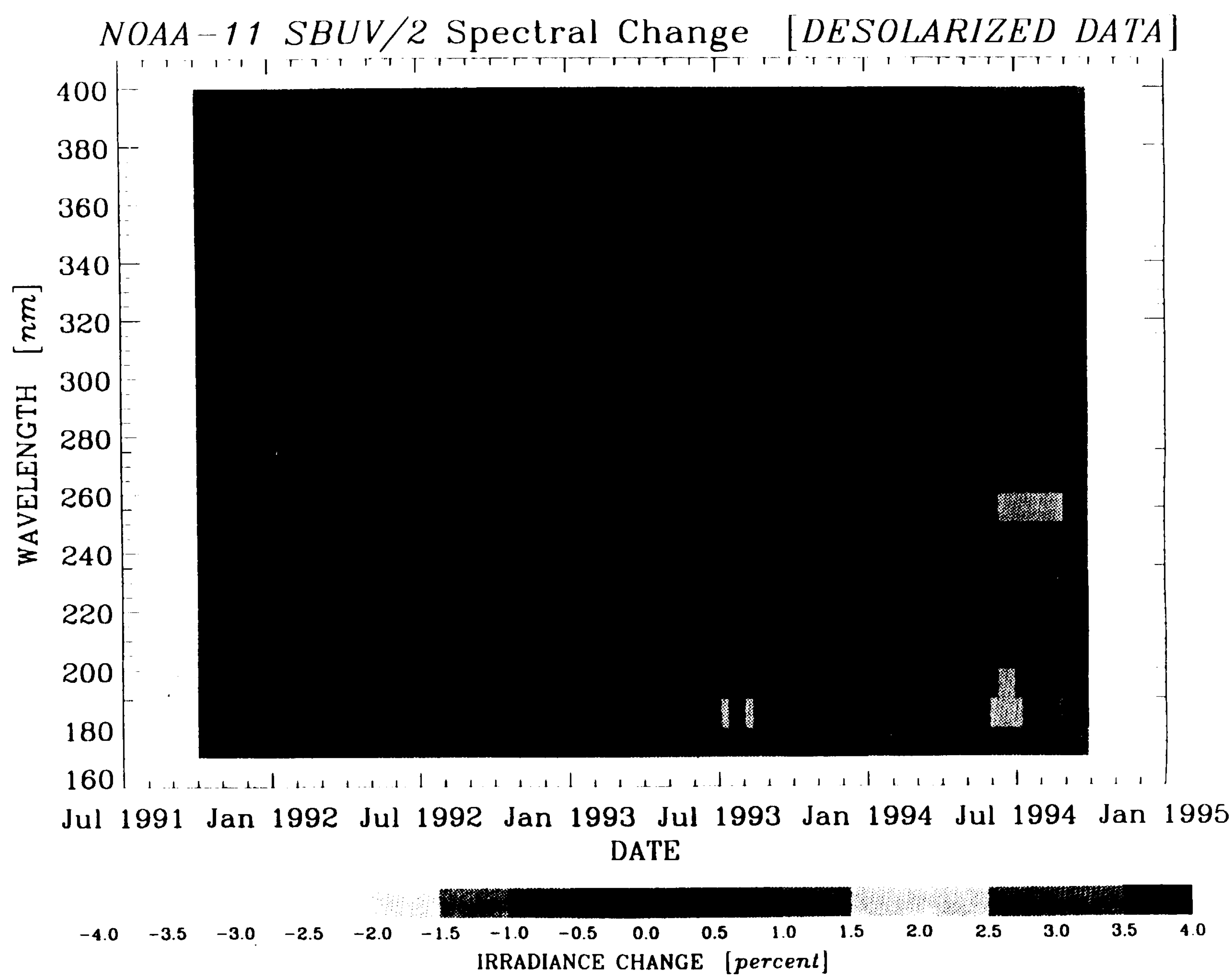
Irradiance Data at 200–208 nm
PREDICTED SOLAR CHANGE Removed
NORMALIZED Irradiance
1.03
1.02
1.01
1.00
0.99
0.98
0.97
NOAA–11
SUSIM [V19]
SOLSTICE [V8]
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE

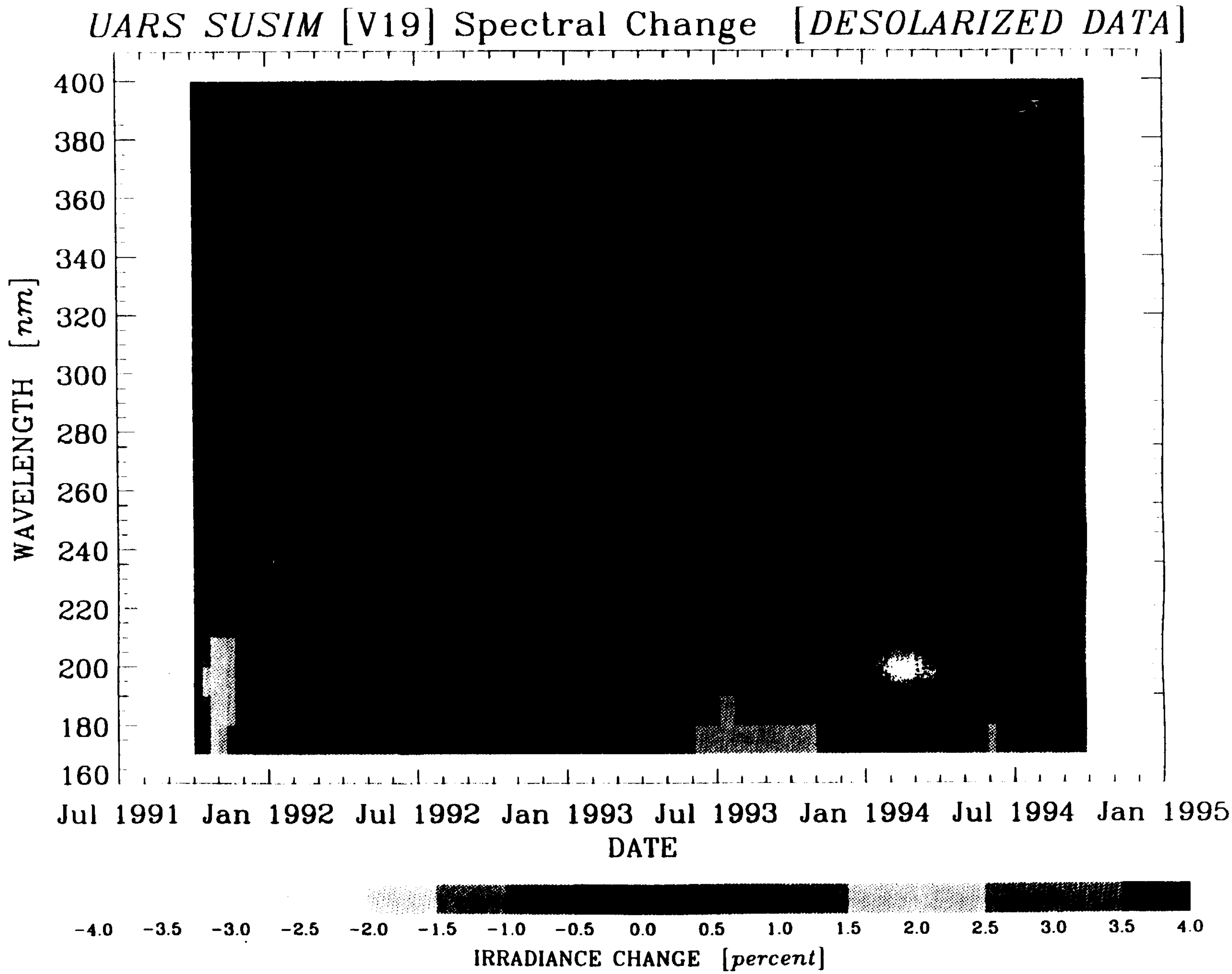
- For full comparison, remove predicted solar change from all 10 nm bands and plot together

  - **NOAA-11** data mostly within ±1% range, with drift of +1-2% at $\lambda < 200$ nm [*light green*]; These data represent later part of NOAA-11 data record

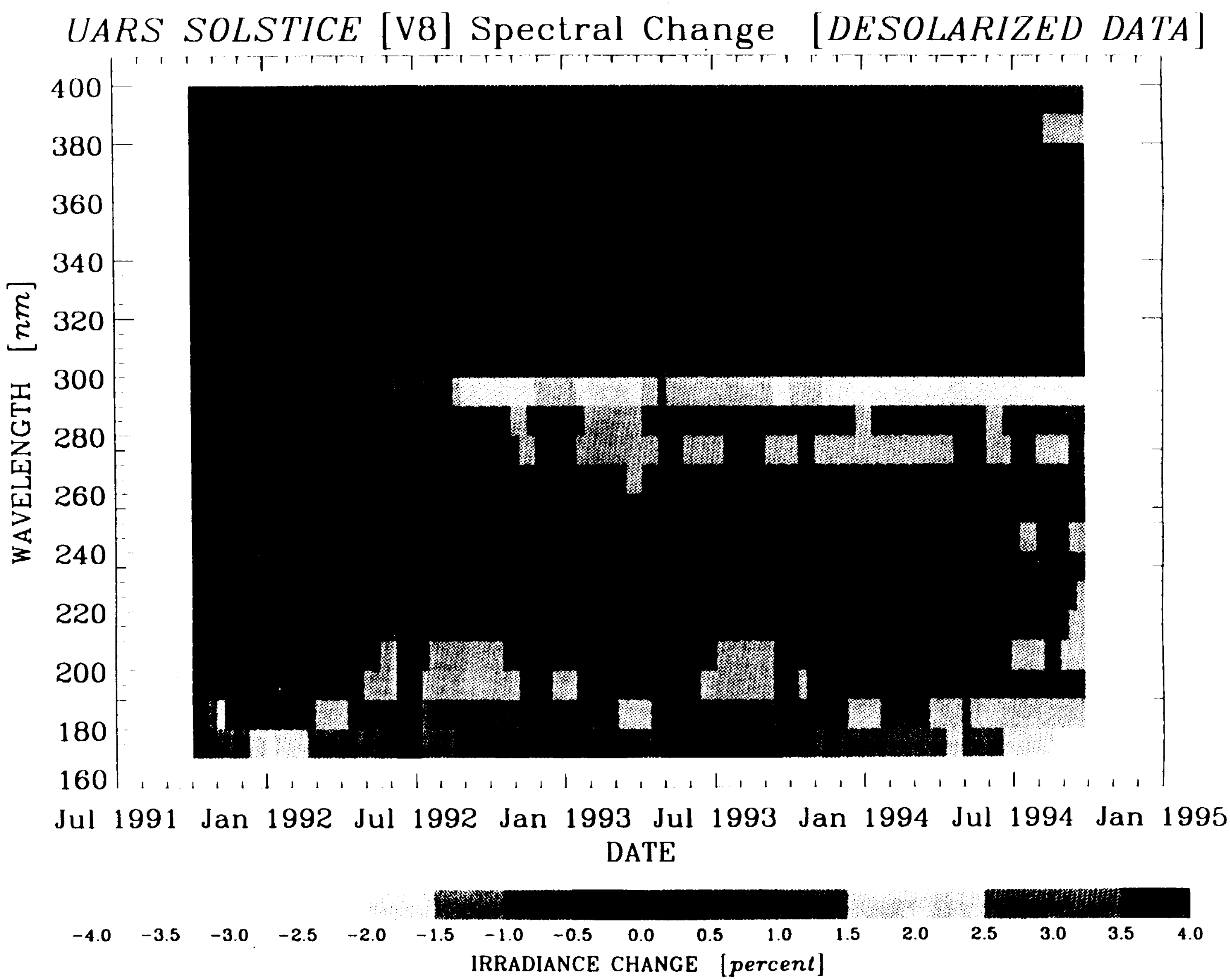
  - **SUSIM** data fall in ±1% range, except for early dip at $\lambda < 230$ nm [*yellow*] and additional drift at 170-190 nm

  - **SOLSTICE** data good to ~1% at 300-380, 220-260 nm; Drifts of –2% or more present in 260-300 nm region, particularly 290 nm [*yellow*]; Data for $\lambda < 210$ nm have positive drift, reaching ΔF = 3-4% at 180-190 nm [*blue*]


NOAA-11 SBUV/2 Spectral Change [DESOLARIZED DATA]
WAVELENGTH [nm]
400
380
360
340
320
300
280
260
240
220
200
180
160
Jul 1991
Jan 1992
Jul 1992
Jan 1993
Jul 1993
Jan 1994
Jul 1994
Jan 1995
DATE
-4.0
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
IRRADIANCE CHANGE [percent]



UARS SUSIM [V19] Spectral Change [DESOLARIZED DATA]
WAVELENGTH [nm]
400
380
360
340
320
300
280
260
240
220
200
180
160
Jul 1991
Jan 1992
Jul 1992
Jan 1993
Jul 1993
Jan 1994
Jul 1994
Jan 1995
DATE
-4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
IRRADIANCE CHANGE [percent]


UARS SOLSTICE [V8] Spectral Change [DESOLARIZED DATA]
WAVELENGTH [nm]
400
380
360
340
320
300
280
260
240
220
200
180
160
Jul 1991
Jan 1992
Jul 1992
Jan 1993
Jul 1993
Jan 1994
Jul 1994
Jan 1995
DATE
-4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
IRRADIANCE CHANGE [percent]

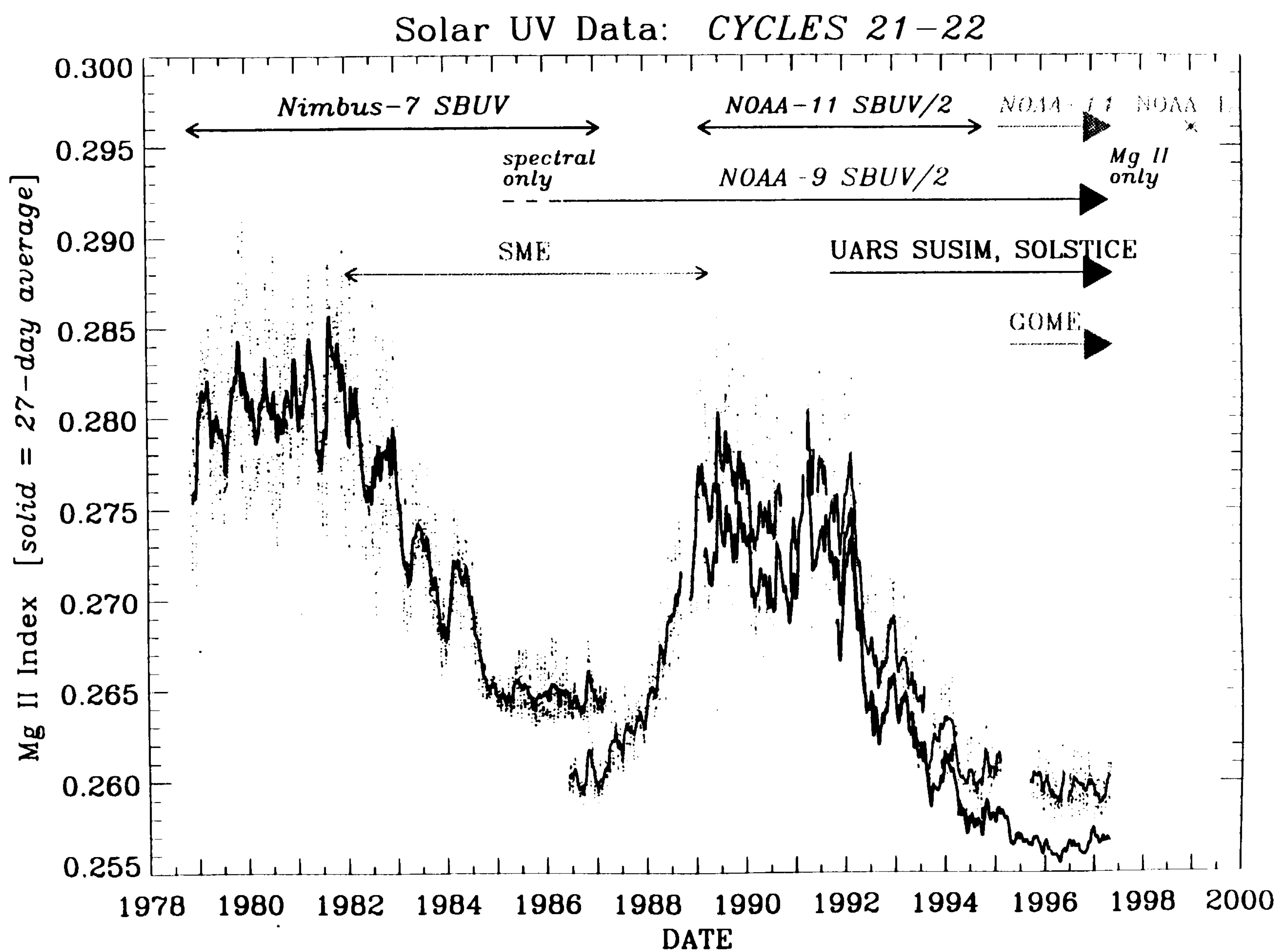
- NOAA-11 solar spectral irradiance data [170-400 nm, December 1988 - October 1994] have been processed with full corrections based on SSBUV coincident data

- Results have long-term accuracy of ±1% at most wavelengths; Solar change from late 1989 (maximum of Cycle 22) to October 1994 (close to minimum) ≈ –(6-7)% at 200-208 nm, –(3-4)% at 240-250 nm

- Comparisons with coincident UARS data during 1991-1994 show that NOAA-11 irradiance data have comparable long-term accuracy, representation of short-term variations

- NOAA-11, NOAA-9 discrete Mg II index data and Mg II scale factors now available at anonymous FTP site [*ssbuv.gsfc.nasa.gov*]; **NOAA-11 spectral irradiance data will be available on-line in Summer 1997**

CONCLUSIONS



Solar UV Data: CYCLES 21-22
Nimbus-7 SBUV
NOAA-11 SBUV/2
spectral only
NOAA-9 SBUV/2
Mg II only
SME
UARS SUSIM, SOLSTICE
GOME
Mg II Index [solid = 27-day average]
DATE
0.300
0.295
0.290
0.285
0.280
0.275
0.270
0.265
0.260
0.255
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000

SSBUV and NOAA-11 SBUV/2 Solar Variability Measurements

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presented at the ICMA Workshop

"Solar Activity Effects on the Middle Atmosphere"

Prague, Czech Republic

18-22 August 1997

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SBUV/2 Instrument Description

- Nadir-viewing double monochromator, wavelength range 160-405 nm, resolution 1.1 nm; Measures backscattered radiance at 12 discrete wavelengths between 252-340 nm for ozone derivation
- Solar measurements made using diffuser plate; Daily measurements are spectral scan (160-405 nm, $\Delta\lambda \approx 0.15$ nm), discrete Mg II (280 nm)

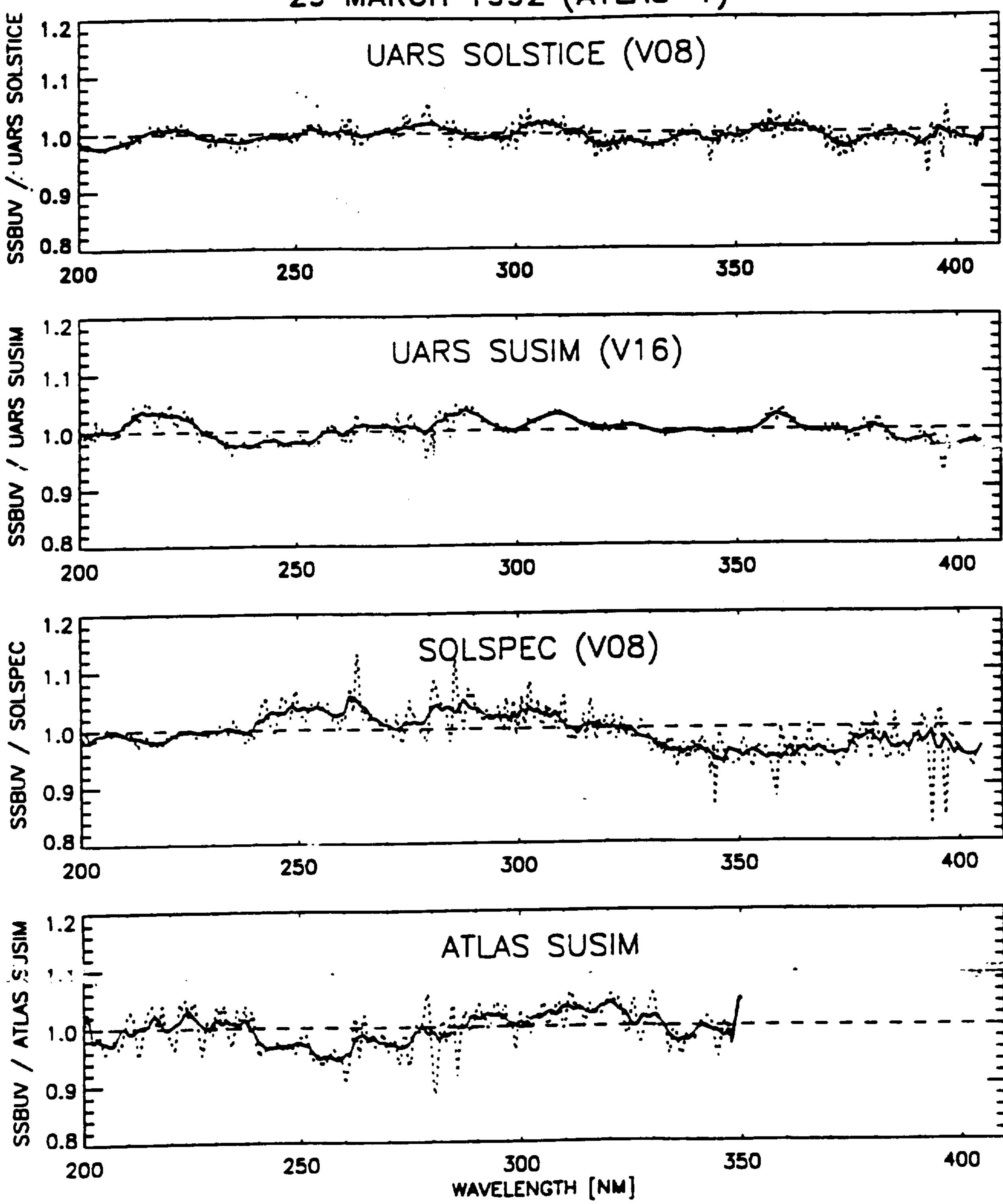
SBUV/2 Flight History

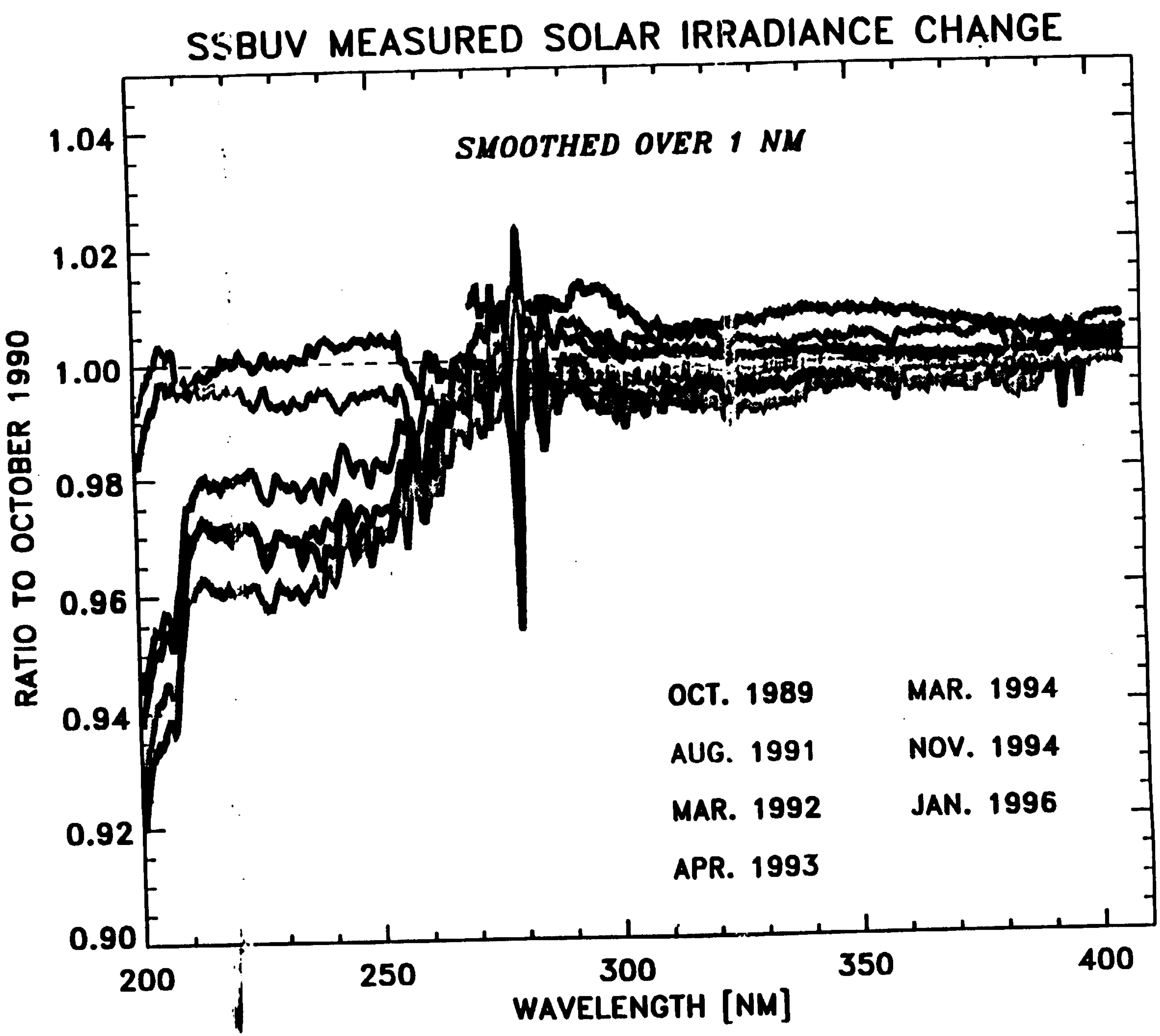
- *NOAA-9*: Ozone and spectral solar data March 1985 - July 1997; Currently acquiring Mg II data only
- *NOAA-11*: Ozone data December 1988 - March 1995, solar data December 1988 - October 1994 (diffuser failure)
- *NOAA-14*: Ozone data February 1995 - present, spectral solar data February - August 1995

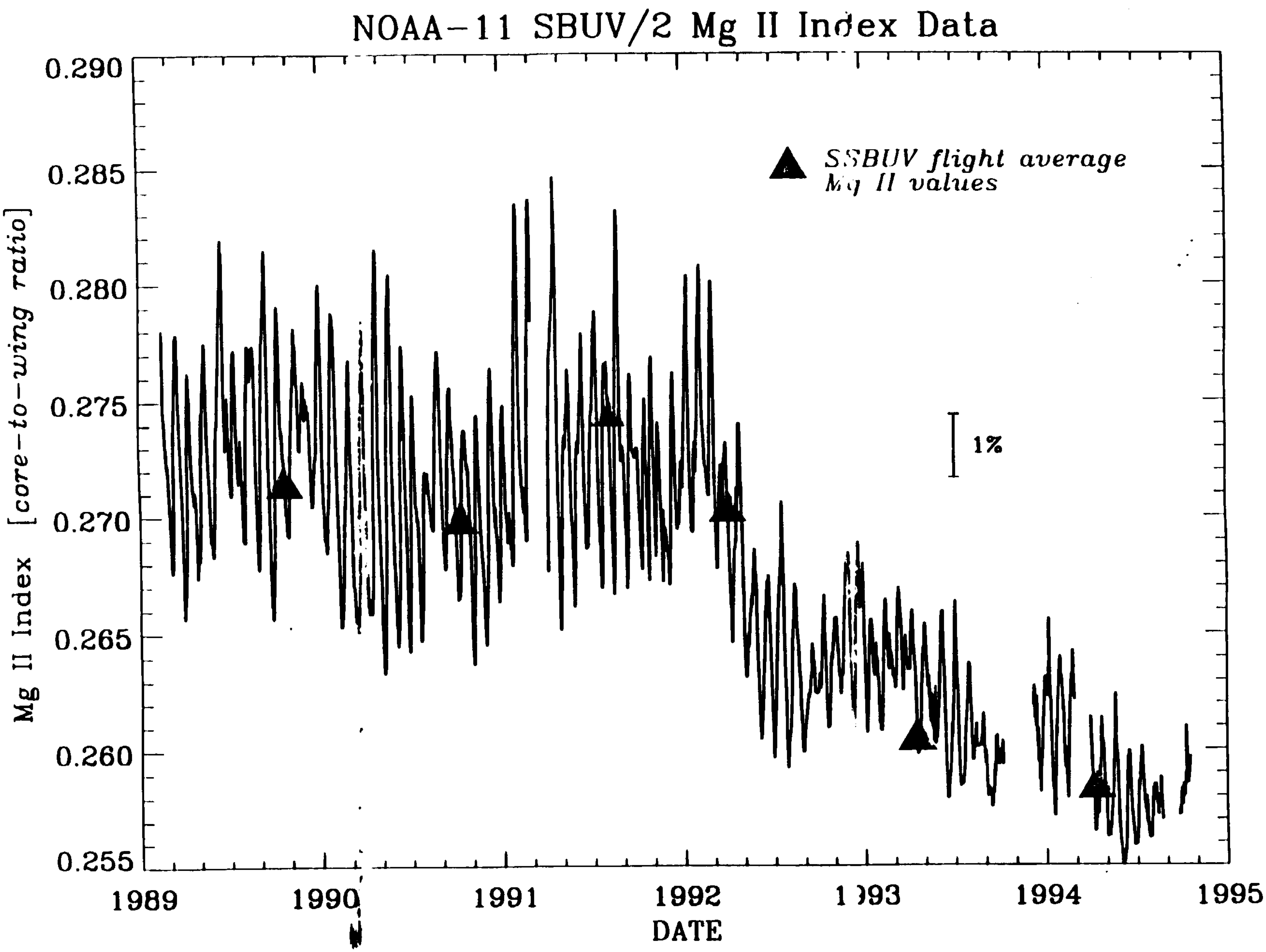
SSBUV Instrument

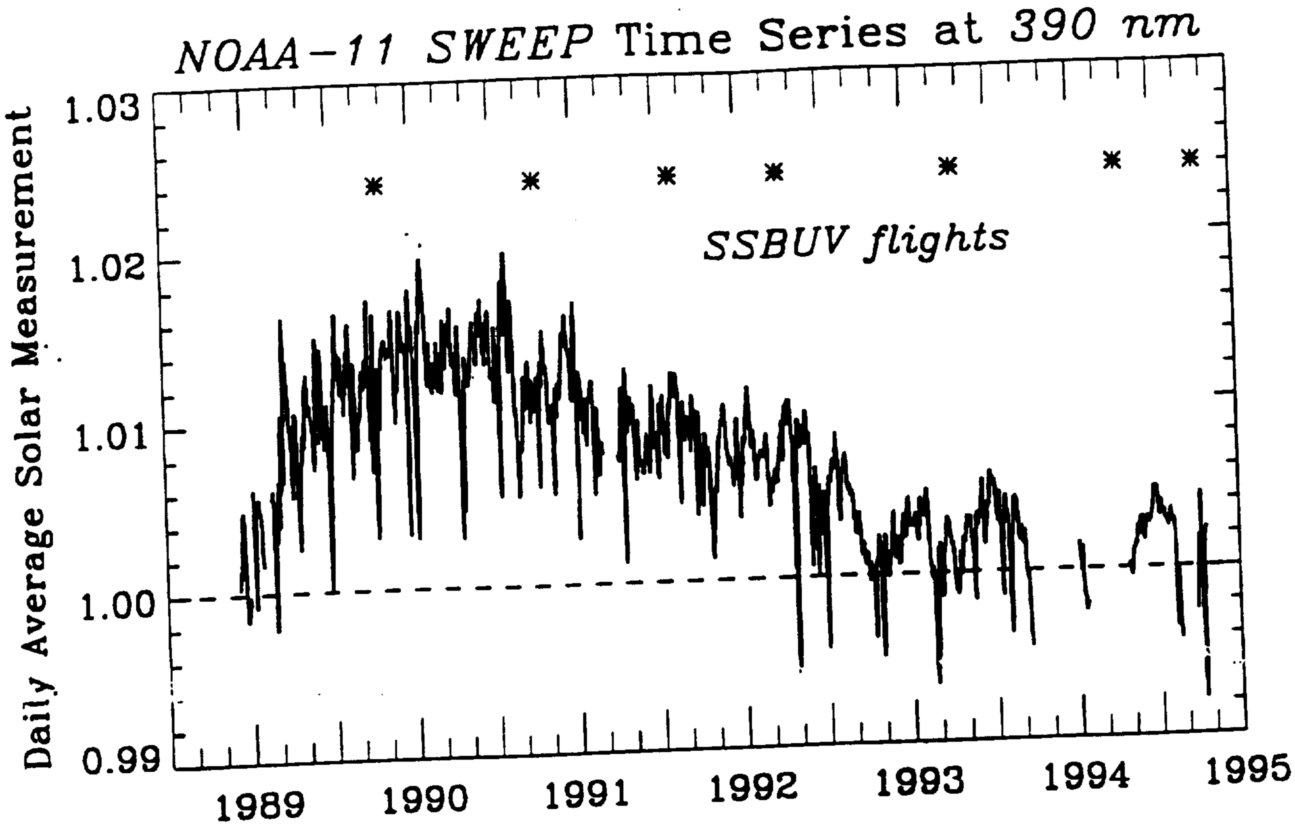
- Engineering model of SBUV/2 instrument, refitted with transmission diffuser for Shuttle operations; Designed to validate SBUV/2 data using coincident measurements, rigorous calibration program
- 8 flights made between October 1989 - January 1996; Three flights as part of ATLAS payload

SOLAR IRRADIANCE COMPARISONS
29 MARCH 1992 (ATLAS-1)

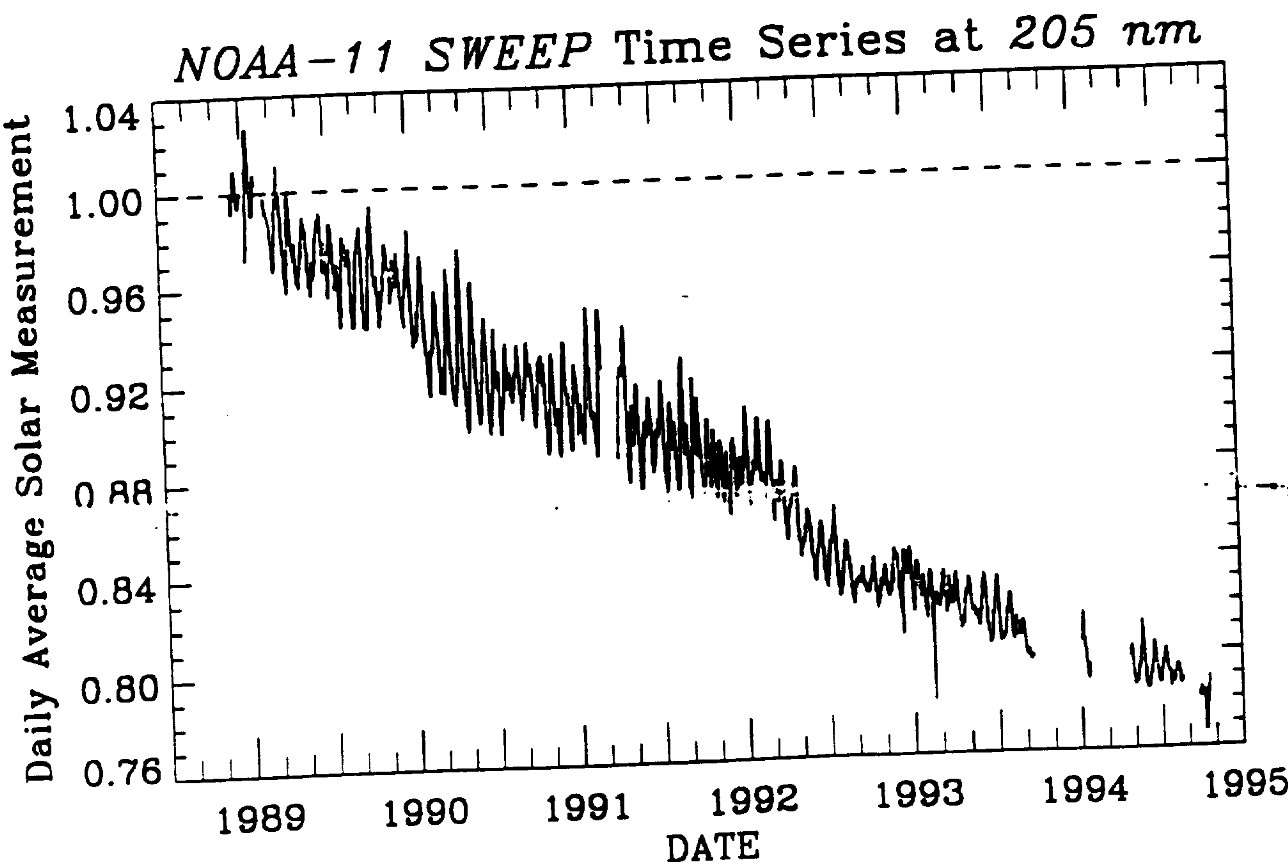



SSBUV MEASURED SOLAR IRRADIANCE CHANGE
SMOOTHED OVER 1 NM
RATIO TO OCTOBER 1990
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
200
250
300
350
400
WAVELENGTH [NM]
OCT. 1989
AUG. 1991
MAR. 1992
APR. 1993
MAR. 1994
NOV. 1994
JAN. 1996

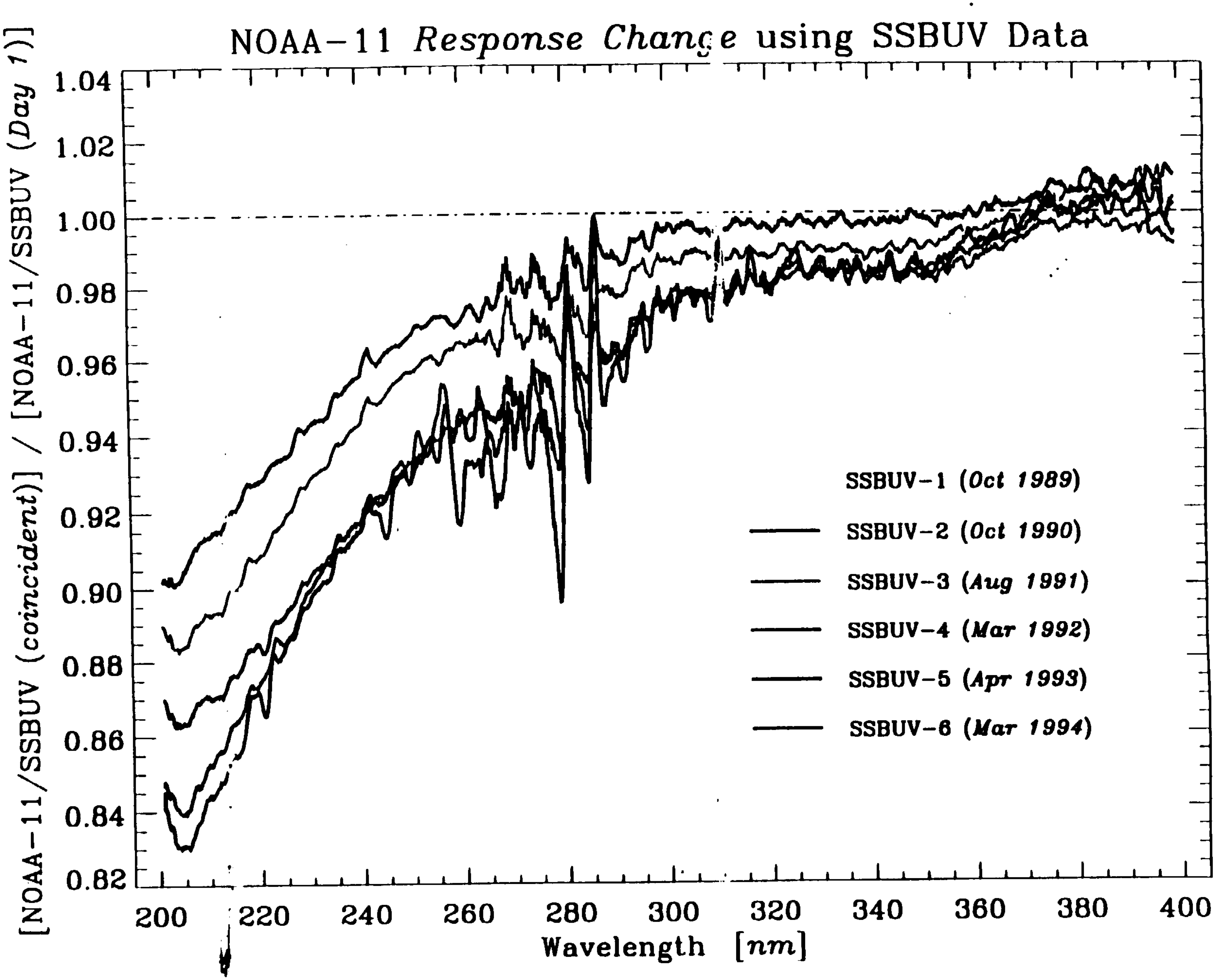

NOAA-11 SBUV/2 Mg II Index Data
SSBUV flight average
Mg II values
1%
0.290
0.285
0.280
0.275
0.270
0.265
0.260
0.255
Mg II Index [core-to-wing ratio]
1989
1990
1991
1992
1993
1994
1995
DATE



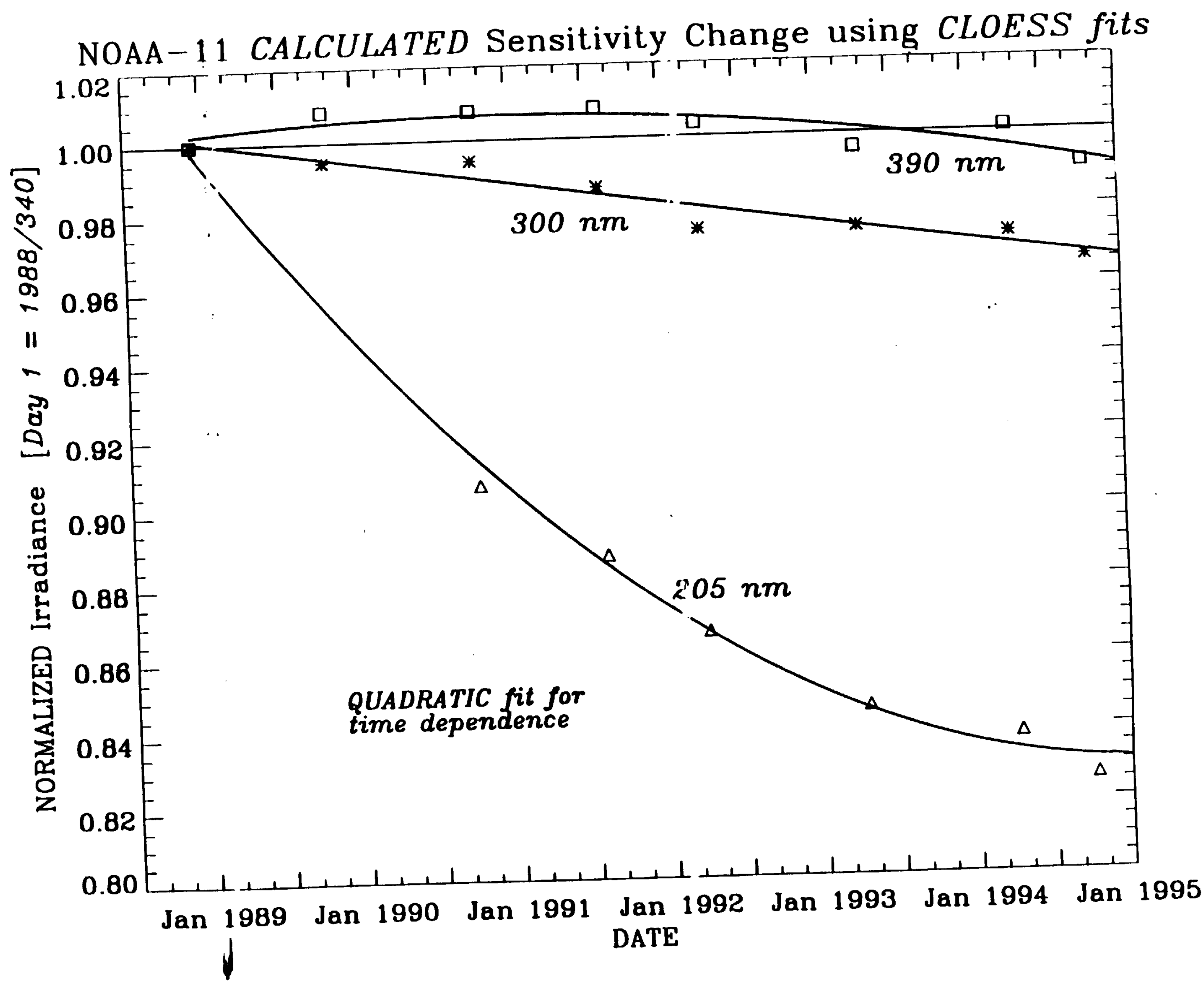
NOAA−11 SWEEP Time Series at 390 nm
Daily Average Solar Measurement
1.03
1.02
1.01
1.00
0.99
SSBUV flights
1989
1990
1991
1992
1993
1994
1995

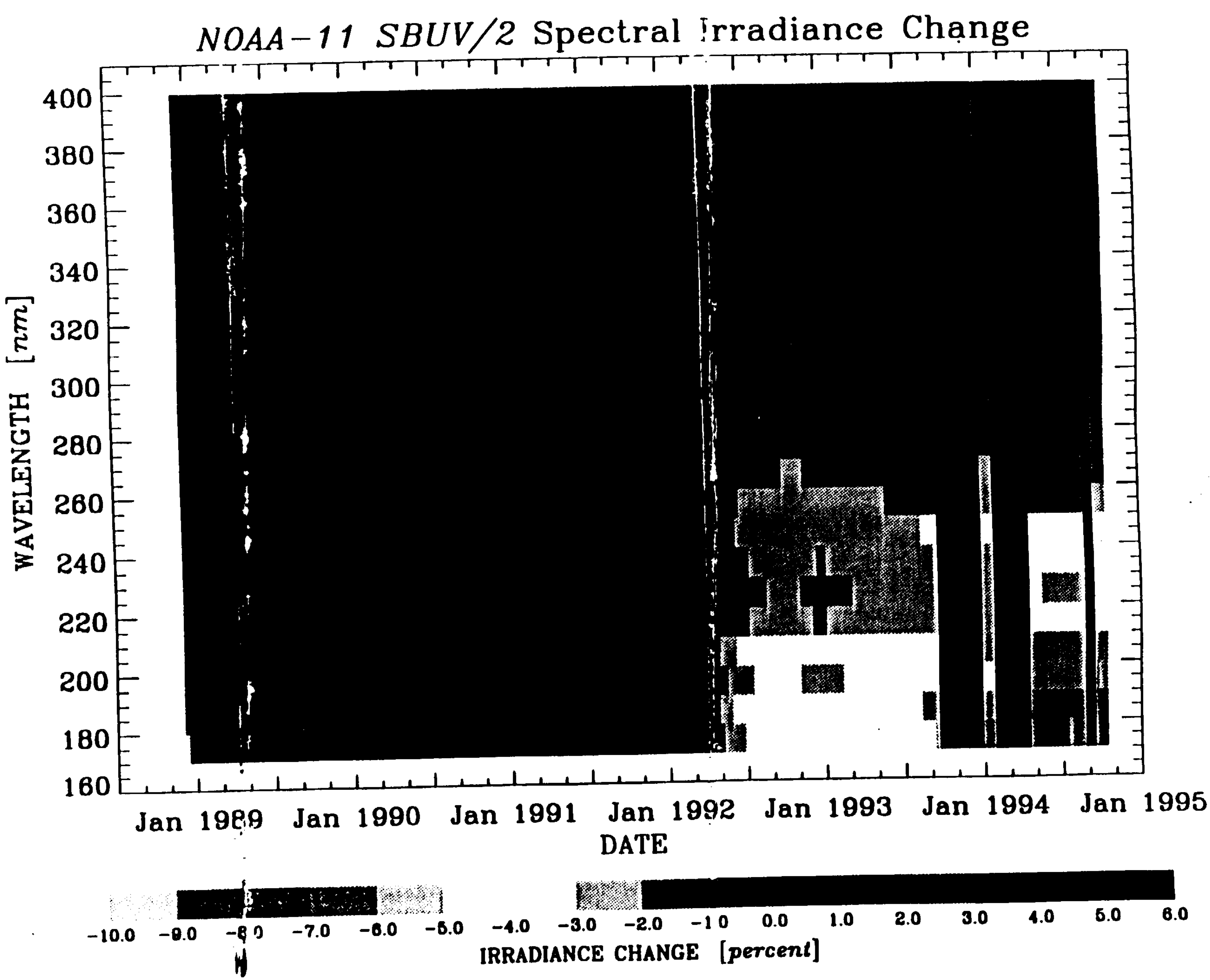


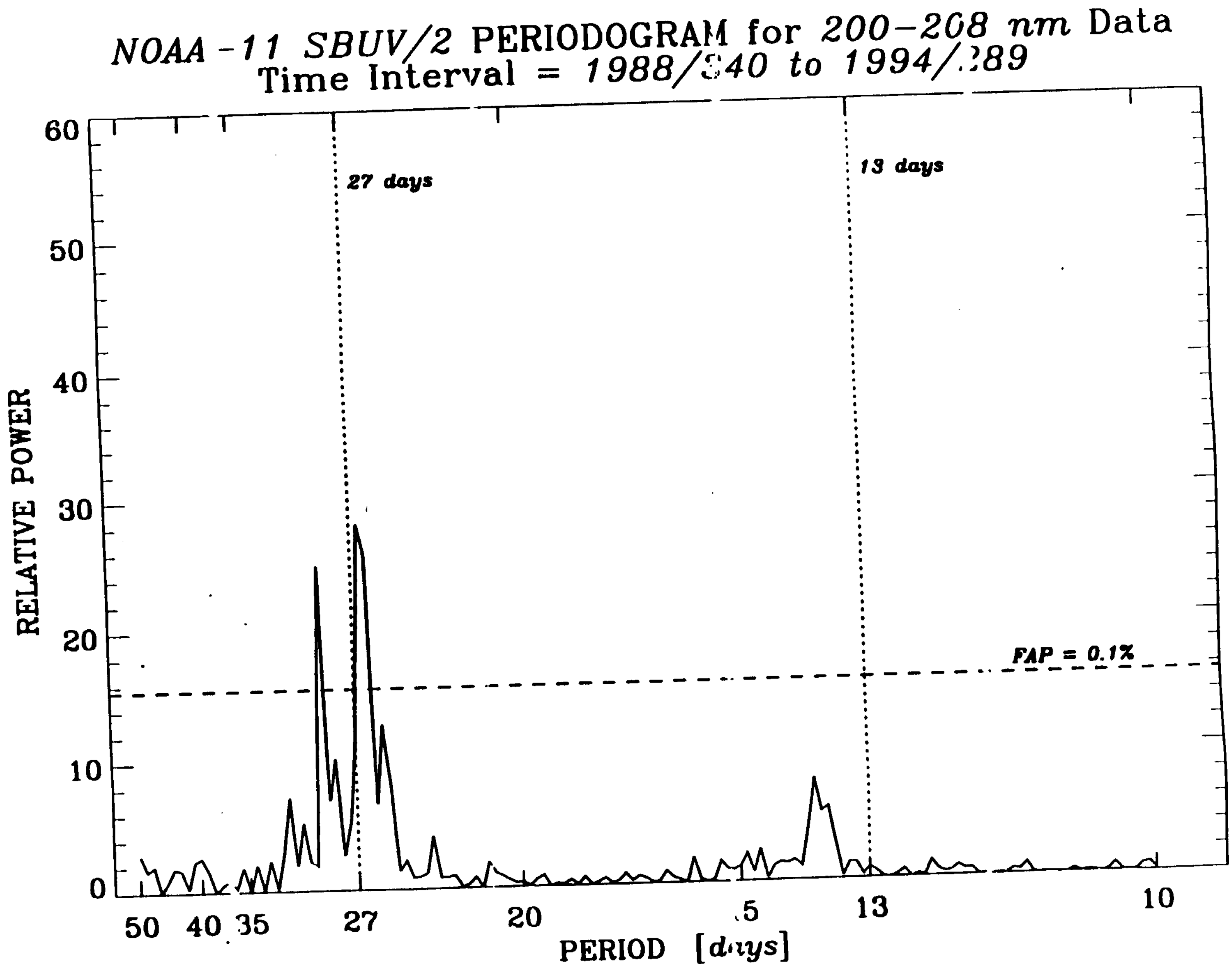
NOAA−11 SWEEP Time Series at 205 nm
Daily Average Solar Measurement
1.04
1.00
0.96
0.92
0.88
0.84
0.80
0.76
1989
1990
1991
1992
1993
1994
1995
DATE

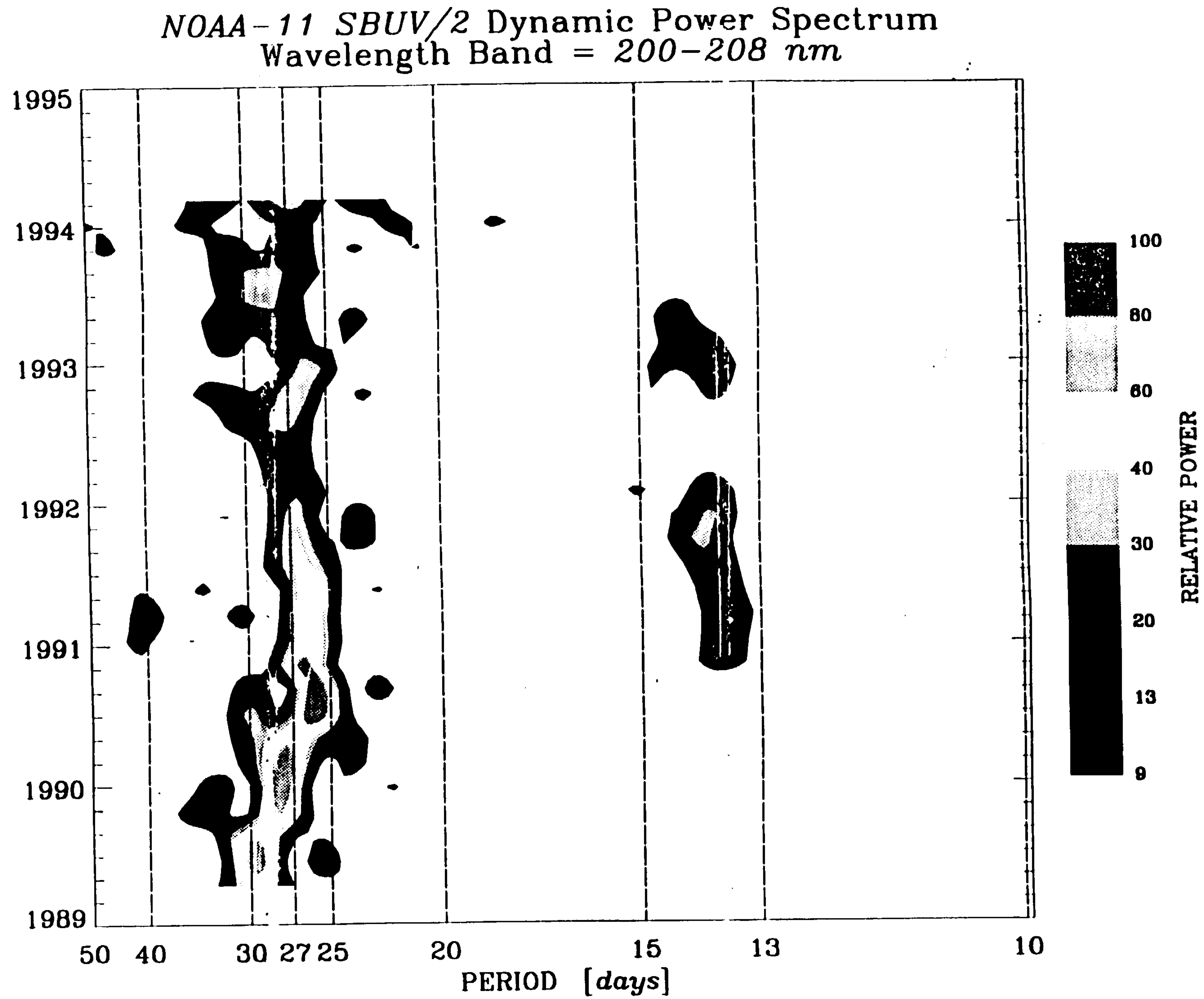


NOAA-11 Response Change using SSBUV Data
[NOAA-11/SSBUV (coincident)] / [NOAA-11/SSBUV (Day 1)]
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
200
220
240
260
280
300
320
340
360
380
400
Wavelength [nm]
SSBUV-1 (Oct 1989)
SSBUV-2 (Oct 1990)
SSBUV-3 (Aug 1991)
SSBUV-4 (Mar 1992)
SSBUV-5 (Apr 1993)
SSBUV-6 (Mar 1994)

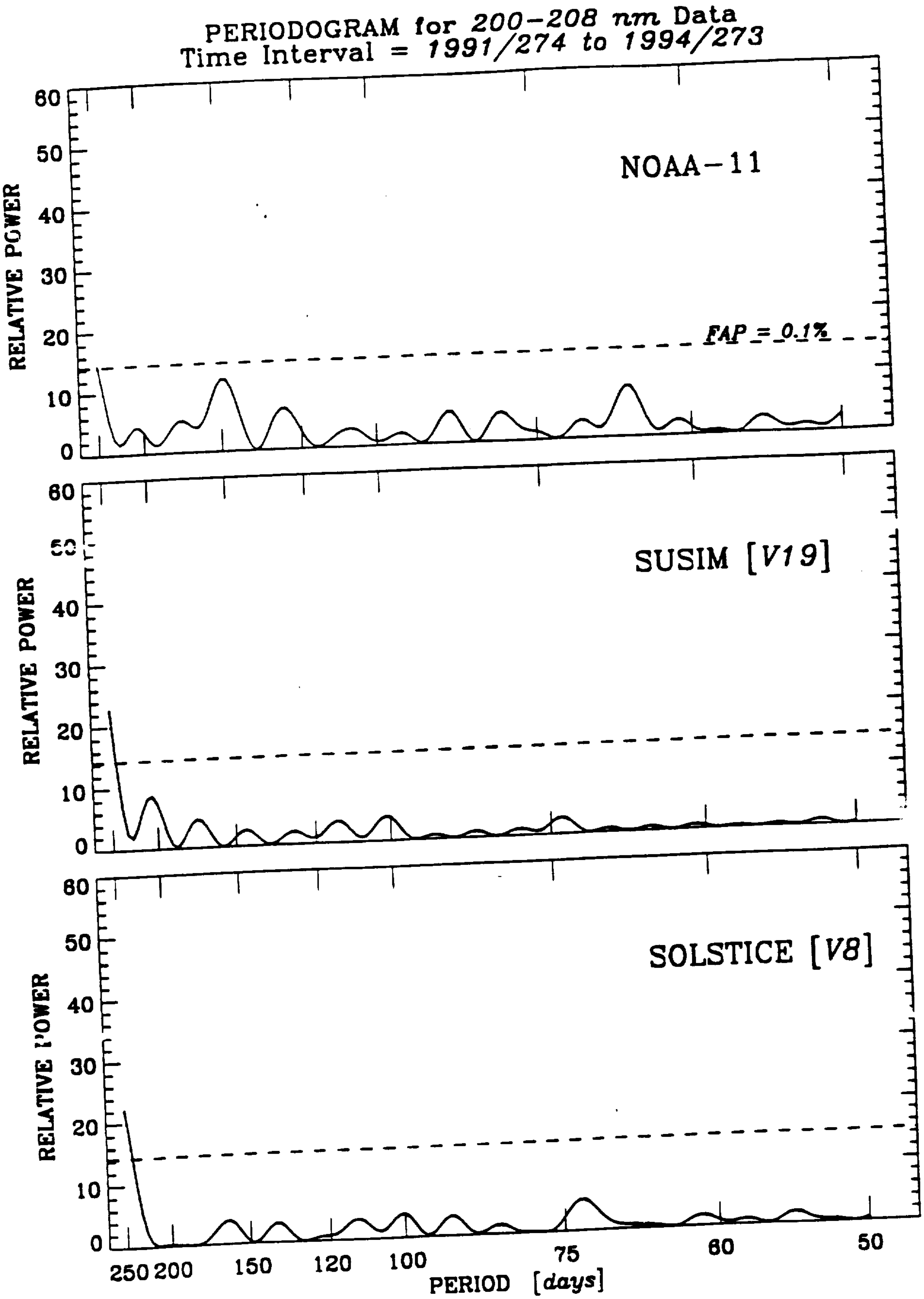

NOAA-11 CALCULATED Sensitivity Change using CLOESS fits
NORMALIZED Irradiance [Day 1 = 1988/340]
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
390 nm
300 nm
205 nm
QUADRATIC fit for
time dependence
Jan 1989
Jan 1990
Jan 1991
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE

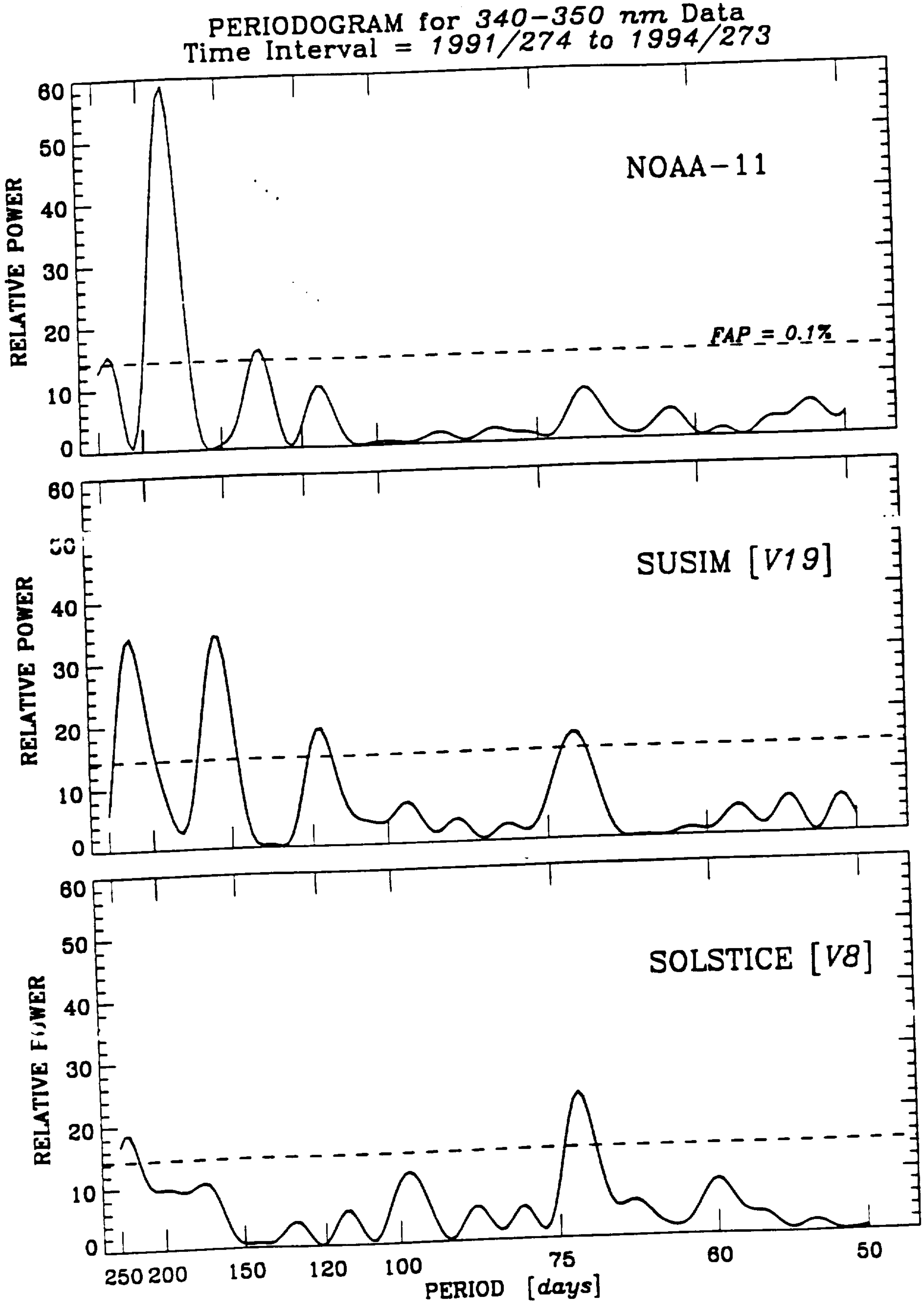

NOAA-11 SBUV/2 Spectral Irradiance Change
WAVELENGTH [nm]
400
380
360
340
320
300
280
260
240
220
200
180
160
Jan 1989
Jan 1990
Jan 1991
Jan 1992
Jan 1993
Jan 1994
Jan 1995
DATE
-10.0
-9.0
-8.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
IRRADIANCE CHANGE [percent]


NOAA -11 SBUV/2 PERIODOGRAM for 200–208 nm Data
Time Interval = 1988/340 to 1994/289
27 days
13 days
FAP = 0.1%
RELATIVE POWER
0
10
20
30
40
50
60
50
40
35
27
20
15
13
10
PERIOD [days]



NOAA-11 SBUV/2 Dynamic Power Spectrum
Wavelength Band = 200-208 nm
1995
1994
1993
1992
1991
1990
1989
50
40
30
27
25
20
15
13
10
PERIOD [days]
100
80
60
40
30
20
13
9
RELATIVE POWER


PERIODOGRAM for 200–208 nm Data
Time Interval = 1991/274 to 1994/273
NOAA–11
FAP = 0.1%
SUSIM [V19]
SOLSTICE [V8]
RELATIVE POWER
0
10
20
30
40
50
60
250
200
150
120
100
75
60
50
PERIOD [days]



PERIODOGRAM for 340–350 nm Data
Time Interval = 1991/274 to 1994/273
NOAA–11
SUSIM [V19]
SOLSTICE [V8]
FAP = 0.1%
RELATIVE POWER
0
10
20
30
40
50
60
250
200
150
120
100
75
60
50
PERIOD [days]

Conclusions

- SSBUV and NOAA-11 SBUV/2 have made accurate measurements of long-term and short-term solar UV variability during solar cycle 22

- Long-term variations measured by SSBUV are ~7% at 205 nm, 3% at 250 nm less than 1% longward of 300 nm

- Short-term variations measured by NOAA-11 are dominated by rotational modulation, which varies in period between 26-29 days during cycle; Episodes of 13-day periodicity also observed

- No evidence for medium-term (50-250 days) periodicity in NOAA-11 SBUV/2, UARS SUSIM, UARS SOLSTICE at wavelengths with short-term variability; Periods observed at long wavelengths not repeatable between instruments, likely to be artifacts

- **SSBUV, SBUV/2 solar data available via anonymous FTP:**

ftp ssbuv.gsfc.nasa.gov
login anonymous

cd pub/solar/ssbuv	SSBUV flight average irradiances
cd pub/solar/sbuv2/noaa09	NOAA-9 discrete Mg II index
cd pub/solar/sbuv2/noaa11	NOAA-11 discrete Mg II index, spectral irradiances (soon)

GOME Solar UV/VIS Irradiance Measurements between 1995 and 1997 – First Results on Proxy Solar Activity Studies[1]

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Tables: none
Figures: 6

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Proposed Running Head

GOME Solar Irradiance Measurements 1995–1997

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ABSTRACT. The Global Ozone Monitoring Experiment (GOME) is the first of a series of European satellite instruments monitoring global ozone and other relevant trace constituents in the UV/visible spectral range. On April 20, 1995, the European Space Agency (ESA) launched the GOME from Kourou, French Guyana, aboard the second European Remote Sensing satellite (ERS-2). In order to obtain the geometric albedo from the backscattered terrestrial radiance measurements, a solar irradiance measurement sequence in the spectral range between 240nm and 790nm is carried out once every day. The GOME solar irradiance is recorded at a moderate spectral resolution (0.2-0.4nm), thus providing an excellent opportunity to contribute to the long-term investigation of solar flux variation associated with the 11-year solar activity cycle from space, which started in 1978 with SBUV (Solar Backscatter UV Experiment) observations on Nimbus-7 and covers solar cycles 21 and 22. This paper briefly describes the GOME spectrometer and measurement mode which are relevant to the solar viewing. Preliminary results from the solar irradiance measurements between 1995 and 1997 and comparisons to SSBUV-8 (Shuttle SBUV) in January 1996 are presented. Solar activity indices used as proxies for solar flux variation are often used to find a correlation with observed variation in atmospheric quantities, for instance, total ozone. Initial results from the GOME MgII (280nm) and CaII K (393nm) solar activity index calculation are presented and discussed. The coupling of solar irradiance variability to global change is a current source of scientific and public concern. This study shows that GOME/ERS-2 (1995–2001) and the next generation of European remote sensing instruments, SCIAMACHY and GOME/METOP, have the potential to provide continuity in the measurements of solar irradiance from space well into the next century.

The Global Ozone Monitoring Experiment (GOME) is the first European passive remote sensing instrument operating in the ultraviolet, visible, and near infrared wavelength regions whose primary objective is the determination of the amounts and distributions of trace atmospheric constituents (Burrows *et al.* 1988a, 1993). The instrument was proposed as a precursor to the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) to be launched on the ENVISAT-1 (1st Environmental Satellite) platform in 1999 (Burrows *et al.* 1988b). GOME is a small scale version of SCIAMACHY observing the atmosphere in nadir sounding only, and having only four spectral channels as opposed to eight channels for SCIAMACHY. The GOME industrial management was funded by the European Space Agency (ESA) and the industrial consortium was led by Officine Gallileo. GOME and SCIAMACHY will provide continuous backscattered radiance and solar irradiance data sets in the UV/visible and near-infrared covering the period between 1995 and 2005 assuming an expected lifetime of five to six years for each instrument.

During the commissioning phase of GOME, which lasted from April 1995 until July 1996, a limited amount of data were processed at the Data Processing and Archiving Facility at the DLR Oberpfaffenhofen (GOMEMANUAL, 1995). The major objective during this phase was the validation of the radiometric accuracy of the GOME solar irradiance and earthshine radiance observations and the validation of trace gas and cloud data products. At the end of June 1996 nominal operation of the GOME processing chain, providing continuous calibrated data products, commenced. Some of the early solar irradiances measured by GOME are shown and compared to preliminary results from the eighth SSBUV experiment in January 1996.

Recent investigations link the 11-year solar cycle to the terrestrial climate (Svensmark and Frijs-Christensen, 1997, see references therein) and variation in total ozone (McCormack and Hood, 1996; Labitzke and van Loon, 1997; and references therein). Solar cycle variation in zonal mean ozone as a function of altitude and latitude have been investigated by Hood (1997) by correlating SBUV and SBUV/2 height-resolved ozone data to the composite MgII index provided by the same instruments (DeLand and Cebula, 1993). Statistical analysis of geopotential height and temperature variation in the lower stratosphere, which show significant correlation to solar activity (Labitzke and van Loon, 1997) strongly indicate that ozone variation in the lower stratosphere and possibly in the upper troposphere are primarily driven by changes in atmospheric dynamics linked to the solar cycle (Hood 1997, Labitzke and van Loon, 1996).

Jackman *et al.* (1996) included the solar cycle variation of the solar flux in a 2D global chemical-transport model and showed that a significant fraction of the fluctuation in the long-term global ozone trend can be related to solar activity. However, two major stratospheric sulphate aerosol events, the volcanic eruptions of El Chichon in 1982 and Mt. Pinatubo in 1991, both occurring near solar maximum, also contribute to the apparent cyclic variation of the annually averaged global ozone and is in phase with the solar forcing (Jackman *et al.*, 1996), since increases in stratospheric sulphate aerosols as well as declining solar activity following solar maximum are associated with observed ozone decreases beyond the anthropogenic trend. The space observations are currently limited to the last two solar cycles, because continuous monitoring of global atmospheric ozone and solar irradiance, starting with Nimbus-7 observations (TOMS, SBUV, ACRIM) has been only available since 1978, which covers just two complete solar cycles up to now. The stratospheric sulphate aerosol issue just mentioned demonstrates the need to extend the solar and global atmospheric monitoring in order to improve the statistics by additional solar cycle observations, which in

turn will permit a better understanding of the coupling between solar activity and global change. GOME was launched in 1995 during the solar minimum following solar cycle 22. If as anticipated, GOME and SCIAMACHY are fully operational, both instrument alone will provide complete coverage of the next solar cycle 23.

The advantage of using proxy solar activity indicators rather than directly measured solar flux variations is that they are less sensitive to long-term instrumental drifts and more easily available. One important goal of this paper is to demonstrate the feasibility of deriving proxy solar activity indices from GOME's daily solar irradiance measurements, which will complement and possibly extend solar activity indices, particularly the MgII index, as derived from other satellite instruments such as the SBUV/2 series (Solar Backscattered UV Experiment, Cebula *et al.* 1988, 1992, 1997, Donnelly, 1991, DeLand and Cebula, 1993, 1997) and the UARS (Upper Atmosphere Research Satellite) instruments, SUSIM (Solar UV Spectral Irradiance Monitor, Brueckner *et al.*, 1996, Floyd *et al.*, 1997a) and SOLSTICE (Solar Stellar Irradiance Comparison Experiment, de Toma *et al.*, 1997).

A preliminary MgII solar activity index and CaII K emissivity index are presented and shown to correlate well with SUSIM results, although the comparison is limited to a nine month period at solar minimum condition (July 1996–March 1997). The high quality of the GOME solar activity indices was achieved only after adjusting the absolute radiometric calibration of the GOME spectra to account for an observed etalon fringe pattern in the GOME spectra. The etaloning is caused by a Fabry-Perot effect observed in a thin quartz layer protecting the detector arrays, which rapidly changes its shape when turning on the detector coolers following an accidential detector warm-up to an ambient temperature near the freezing point. On the other hand the GOME MgII core-to-wing ratio, used as a solar activity indicator, proved to be rather insen-

sitive to the observed UV degradation, the latter being a common problem of UV measuring instruments in space. This paper concludes with some remarks about GOME and its importance to future space missions for monitoring daily solar flux variations.

INSTRUMENT DESIGN

The GOME instrument is a double monochromator which combines a pre-disperser prism and a grating in each of the four channels as dispersing elements. A schematic diagram of the GOME optical layout is shown in Fig. 1. The irradiance and radiance spectra are recorded with four linear Reticon Si-diode arrays with 1024 spectral elements each. Peltier elements attached to the diode arrays and connected to passive deep space radiators cool the detectors to about $-40°$C. Except for the scan mirror at the nadir view port, all spectrometer parts are fixed and the spectra are recorded simultaneously from 240nm to 790nm. The spectral resolution varies between 0.2nm (UV, Channel 1) and 0.4nm (VIS, channel 4). Part of the light that reaches the pre-disperser prism is branched out and recorded with three broadband polarization monitoring devices (PMD), which approximately cover the spectral ranges of the detector arrays in channels 2 (300-400nm), 3 (400-600nm), and 4 (600-800nm), respectively. The PMDs measure the amount of light at an instrument defined polarization angle.

A calibration unit adjacent to the spectrometer part consists of the sun view port and a compartment housing a Pt/Ne/Cr hollow cathode discharge lamp. The solar radiation is attenuated by a mesh (20% transmission) and directed via a diffuser plate (wet-sanded Al plate with Cr/Al coating) on to the entrance slit of the spectrometer. When no solar measurements are carried out and during nadir and calibration lamp measurements, a protective shutter is

placed in front of the solar view port in order to avoid unnecessary UV exposure and to prevent straylight from entering the instrument. The calibration unit becomes optically coupled to the spectrometer by proper positioning of the scan mirror. The various pointing geometries of GOME permit, in addition to solar and earth nadir viewing, lunar observations (through the nadir view port with scan mirror angle of about 85 deg.) at selected times during a year.

The processing of the GOME data, which includes the radiometric and wavelength calibration of the spectral raw data, occurs at the German Remote Sensing Data center (DFD) at DLR Oberpfaffenhofen. The on-ground calibration includes adjustment of the GOME irradiances and earthshine spectra to account for leakage current, straylight, focal plane area noise (which is related to the voltage controlling the Peltier coolers), and the pixel-to-pixel variability (which is monitored using on-board LED measurements). The absolute radiometrically calibrated GOME spectra (solar irradiance and backscattered radiances) are then referred to as Level-1 GOME data products. For further details about the GOME Data Processor (GDP) the reader is referred to the GOME Users Manual (GOMEMANUAL, 1995).

SOLAR IRRADIANCE MEASUREMENTS

The ERS-2 satellite moves in a retrograde, sun-synchronous, near polar orbit at a height of about 785 km. Once a day (every fourteenth orbit) GOME solar irradiance measurements are carried out when the ERS-2 satellite crosses the terminator in the north polar region coming from the night side. Since GOME is not equipped to actively track the sun, viewing of the full solar disc is only possible for a time span of about 50 sec. Integration times are 0.75 sec for all channels, except for the UV channel, where the integration time is doubled. A

mean solar spectrum is constructed from the series of measurements during the solar viewing period. Once a month, the internal hollow cathode calibration lamp is switched on over an entire orbit. During this sequence, a series of lamp measurements with and without the solar diffuser permits the investigation of long-term degradation of the sun diffuser and an update in the wavelength calibration of the spectrometer, respectively. During the GOME commissioning phase, no significant long-term drift in the wavelength calibration was observed.

Prior to launch, the spectral irradiance of the GOME flight model was calibrated by the Dutch firm TPD using a 1000 Watt FEL lamp, which in turn was referenced to an absolute standard at NIST. The absolute accuracy of the NIST standard is quoted to be 1 to 3% in the range 250-340nm (Walker *et al.*, 1987). The total calibration error at the shortest GOME wavelength at 240nm is estimated at 4.5% (3σ), where the major contribution comes from the preflight calibration measurements using the 1000W FEL lamp (3.8%) and the determination of the bi-directional scattering distribution function (BSDF) of the diffuser plate (2.2%).

A calibrated mean solar spectrum measured by GOME on July 22, 1995, is shown in Fig. 2. A qualitative comparison of solar irradiance measurements in the GOME channel 2 with preliminary results from the eighth shuttle SBUV experiment in January 1996 is shown in Fig. 3. The GOME spectrum has been convolved with a 1.1nm FWHM (full width half maximum) triangular function, which best approximates the SSBUV slit function. The most significant feature in the GOME/SSBUV ratio is an etalon structure, with fringe maxima separated by about 13 nm. Similar features are observed in the other channels. Calculations show that the protective 3μm SiO_2 layer covering the light sensitive area of each detector array is responsible for creating the Fabry-Perot pattern. This was already known from the pre-flight calibration and characterization program. Apart from the etalon pattern, the agreement between SSBUV and GOME in

the wavelength range 312–400nm (GOME channel 2) is on average better than 2%, which is within the maximum calibration uncertainty of 4.5% at 240nm and 3.2% between 300 and 400nm estimated for GOME (GOMECAL, 1994). It should be noted here, that the SSBUV instrument exhibited excellent agreement with other satellite and shuttle-based measurements (Cebula *et al.*, 1996, Woods *et al.*, 1996).

In the first few days after the Peltier elements are switched off and on, the fringe patterns change rapidly, with irradiance deviations up to 4% (Eisinger *et al.*, 1996) between consecutive days. Within a week, the etalon fringes stabilize. During the warm-up phase, the detector may reach the ambient temperature of the focal plane area, which is near 0°C. The cooling of the detector following the warm-up is speculated to produce a thin ice layer on top of the SiO_2 layer. The solar irradiance ratios show that the periodicity of the fringe pattern remains constant, which is expected if one assumes that condensed ice makes up only a fraction of the quartz layer size and that the etalon period is determined by the quartz thickness. However, solar ratios taken before and after such cooler switching events indicate fringe amplitude changes of several percent. A possible explanation is that the thin condensing layer may act as a reflection coating altering the optical efficiency of the quartz etalon. Without correcting for the shifting etalon, the solar activity index time series derived from the spectral irradiance in the core of a Fraunhofer line, such as MgII (280nm) or the CaII *k* and *h* lines (393–396nm), experience sharp discontinuities after the cooler switching. As shown in the next section, the application of an etalon correction scheme successfully removes the discontinuities.

From the comparison of calibrated GOME UV spectra with the mean SSBUV-8 irradiance, a spectral degradation related to extended exposure of the optical components in the spectrometer to the harmful UV radiation was observed. A monotonic decrease in the GOME UV irradiances has been observed

in GOME channel 1 (240–315nm) since the beginning of July 1995. In January 1996, the GOME irradiances at 240nm had decreased by 20%, at 245 nm by 15%, and at 273nm by 8%. The diffuser reflectivity measurements have not revealed a systematic degradation trend since launch. However, the precision of using the diffuser reflectivity measurements up to June 1997 is limited to 20% in the UV channel (channel 1: 240–315nm) and better than 5% in GOME channels 2–4 (315–795nm). The UV degradation was also observed in the lunar spectra, which are recorded from light entering the nadir view port (Dobber, 1997). This means that the loss in optical efficiency is primarily occurring in the spectrometer part (see Fig. 1) and, since the nadir scan mirror is the most exposed spectrometer optical element, it is likely that this mirror is mostly affected.

The in-flight calibration measurements, i.e. relative intensities of reference lines recorded with the internal Pt/Cr/Ne calibration lamp, which is primarily used as a wavelength standard, and the lunar observations have not yet been used to correct for instrument degradation with time. A first in-flight calibration based upon intensity ratios derived from the lamp line measurements, which were referenced to pre-flight lamp measurements, was carried out in the beginning of the commissioning phase (Hoekstra *et al.* 1996), but no further update has occurred since July 2, 1995. For the investigation of the proxy solar activity based upon individual Fraunhofer lines, a simple recalibration of the UV channel spectra (240–400nm) to account for UV degradation has been applied by referencing the GOME irradiance to the SSBUV-8 measurements in January 1996, as will be described in the next section.

GOME PROXY SOLAR ACTIVITY INDICES

The original definition of the core-to-wing ratio which was coined the MgII index uses a total of seven wavelength positions about the MgII absorption near 280nm. This definition was first successfully applied to SBUV/Nimbus-7 data by Heath and Schlesinger (1986). Because of the enhanced spectral resolution of GOME in the UV Channel ($\Delta\lambda = 0.17$nm) as compared to the SBUV series ($\Delta\lambda \cong 1.1$nm) the GOME MgII index is here calculated using 10 spectral values as explained in Fig. 4. During solar maximum of the 11-year solar cycle, the number of sunspots increases. Associated with the dark photospheric sunspots are chromospheric plages, which are hotter than the surrounding areas and are responsible for the chromospheric emission observed in the core of Fraunhofer absorption lines. The formation of the wing of the Fraunhofer lines originates in the photosphere, where the variation with the solar cycle is known to be small. Although the MgII doublet is not spectrally resolved in the GOME spectra, the chromospheric emission peak is recognizable at the position of each peak of the doublet (see Fig. 4). The corresponding residuals of the series of measurements between end of June 1996 and end of March 1997 relative to the solar irradiance from January 14, 1997, as depicted in the bottom of Fig. 4 highlights the variability of the chromospheric emission. The short-term variability of the chromospheric emission is mainly linked to the 27-day rotation of the sun, which moves active regions in and out the field-of-view of the instrument.

A continuous set of calibrated GOME spectra is available since the end of June 1996 and a corrected time series of the GOME MgII core-to-wing ratio for the time period June 28, 1996, to March 31, 1997 is shown in Fig. 5. In the case of the CaII K and H doublet the definition of the transmission background is far more difficult due to the high density of Fraunhofer lines in the spectral region around 390-400nm. For this reason, the CaII K peak irradiance rather than the core-to-wing ratio is displayed as a time series in Fig. 6. In the same figure the peak irradiances of the individual peaks of the MgII doublet are also shown.

Unlike the MgII doublet, the chromospheric emission in the absorption core of CaII Fraunhofer line can not be seen in the spectrum itself, however, a small variation in the peak irradiance is visible in the time series. The modulation of the CaII peak irradiance is a factor of four smaller than the corresponding modulation of the MgII core-to-wing ratio.

As discussed earlier, the GOME solar irradiance values in channel 1 (240–315nm) and channel 2 (312–405nm) have been corrected for the etaloning and UV degradation before deriving the MgII core-to-wing ratio and the CaII *k* peak transmission. A correction to the solar irradiances have been determined by ratioing the GOME measurement to the SSBUV-8 solar irradiance. Both GOME and the mean SSBUV-8 solar spectrum were spline interpolated to a common wavelength grid in steps of 0.1nm and then convolved with a 10nm boxcar, i.e. smoothed, before taking the irradiance ratios. Since the degradation increases monotonically with decreasing wavelength, a third order polynomial generally sufficed to fit a correction curve to the solar ratios, which is then applied to correct the degradation observed in the GOME data.

In the nine month period (July 1996–March 1997), for which proxy solar activity index time series were analyzed, a total of five GOME detector cooler switchings were reported. On two occasions the cooler switching also lead to a warm-up of the detectors near the freezing point (October 29, 1996, and January 14, 1997). Associated with the cooler switching are observed discontinuities in the solar activity indices, which can be on the same order or higher than the modulation observed in the time series. A correction to the shifting etalon patterns was therefore applied by fitting a high order polynomial through the solar irradiance ratios covering about two etalon fringes in the wavelength region 274–287nm. A small window at the core of the MgII doublet (279.5–280.5nm) was excluded from the fit. Similarly, a spectral window between 385nm and 403nm, excluding two 2nm sub-windows centered at the two peaks of the CaII

doublet, were selected in channel 2. The GOME solar ratios were referenced to a GOME spectrum, recorded four hours after a detector switching on January 14, 1997, and which most closely resembled warm detector spectra.

DISCUSSION

The selection of the MgII index and CaII K absorption as surrogates for solar activity variation is not unique. Among the many Fraunhofer lines available in the GOME spectral range, the two candidates here proposed are among the strongest absorption features and are easily observable by GOME at its spectral resolution. Since an operational in-flight calibration routine has not yet been included in the GOME Data Processor, a correction scheme to account for long-term UV degradation effects and the etalon patterns, observed in the GOME channels 1 (240-310nm) and 2 (310-405nm), was implemented. Comparison of the GOME MgII index with the SUSIM MgII index V19r2 (Floyd *et al.*, 1997, Floyd, 1997, see Fig. 5) enables the correction scheme introduced here to be validated.

In Fig. 5 the SUSIM V19r2 index has been scaled by linear regression to the value range of the GOME MgII index. The linear regression equation was determined to be $y = -0.1107(92) + 1.238(35)x$, where the digits in brackets are the uncertainties in the regression coefficients, x, the SUSIM MgII V19r2 index value, and y, the scaled SUSIM index value as plotted in Fig. 5. From the linear regression a correlation coefficient of $r = 0.93$ between the GOME and SUSIM time series was found. At first sight one might consider the correlation to be somewhat low as correlations between SBUV/2, SUSIM, and SOLSTICE time series tend to be on the order of 0.97 or better (de Toma *et al.*, 1997). However, all comparisons were based on data stretching from solar maximum (launch of

UARS in fall 1991) to solar minimum (end of 1995), where the index values have their largest spread. Thus far the GOME time series has been limited to a period during the solar minimum phase between solar cycles 22 and 23. The high correlation between the GOME and SUSIM MgII indices during solar minimum condition proves that the radiometric calibration correction accounting for UV degradation and the shifting etalon pattern works well.

The absolute activity index values and peak irradiances as derived from two instruments generally differ considerably due to differences in the instrumental slit functions and the associated spectral resolution. High correlation between proxy solar activity indices derived from different instruments are important in order to properly transform different series into each other in order to obtain a time series extending beyond the lifetime of a single instrument.

As expected, the MgII solar activity index appears to be rather insensitive to the UV degradation, because the chromospheric emission peak was normalized to the slowly varying photospheric background in the wing region. However, the core-to-wing ratio is found to be very sensitive to the rapid changes in solar irradiances resulting from the etalon fringes shifting after detector cooler switchings. Removal of this effects provides an excellent MgII index from GOME.

CONCLUSION

In the first two years of GOME operation, it has been demonstrated that GOME can provide continuity in long term solar irradiance monitoring from space which was started in the late 1970s. Combining the SBUV and SBUV/2 series (1978–present), the UARS SOLSTICE and SUSIM data (1991–present) and the European series of GOME and SCIAMACHY, long term space monitoring of solar spectral irradiance and its variability during three complete solar cycles, cycles

21, 22, and the upcoming cycle 23, is required to investigate the links between the natural variability of the solar output and global atmospheric processes. The latter may significantly contribute to the global change issue. If a proper correction to the GOME solar irradiance to account for UV degradation in the short wavelength region and the etalon effect is applied, GOME may provide accurate absolute solar irradiances in the UV/visible with an overall calibration uncertainty of 5% and better and with a repeatability of less than 1% on a day-to-day basis. One should also note that GOME is currently the only satellite instrument regularly measuring solar irradiance in the wavelength region beyond 400nm.

A tandem operation of GOME/ERS-2 and SCIAMACHY, an extended GOME version, is planned to provide cross-validation for SCIAMACHY during the first year of SCIAMACHY operation after launch of ESA'S ENVISAT platform in 1999. A second generation GOME instrument is scheduled to fly on METOP, an European operational meteorological satellite being planned by ESA and EUMETSAT. METOP is the European successor to the NOAA/TIROS platform and is planned for launch in 2002. Two SBUV/2 instruments on NOAA-9 and NOAA-14, which are still operational, may provide coverage until 2005. Three new SBUV/2 instruments are planned to fly on three successive missions, NOAA-L, -M, and -N, to be launched two years apart each starting in 1999. SOLSTICE and SUSIM launched in 1991 are still operating and may continue measurements until the turn of the century. A second generation of the SOLSTICE instrument (SOLSTICE II) was originally scheduled in the NASA's EOS-CHEM series, of which the first platform is to be launched in 2002, but has been postponed in the NASA's Mission to Planet Earth restructuring in 1995, unfortunately. Alternative flight opportunities for SOLSTICE II are under consideration. At the moment, the follow-up missions of GOME/ERS-2, SCIAMACHY and GOME/METOP, are likely to be the only new instruments providing daily UV solar flux measurements in the near future.

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Figure Captions

Figure 1. *Schematic Instrumental Setup of GOME.* The GOME instrument is a four channel spectrometer. Attached to the spectrometer is a calibration unit housing a Pt/Cr/Ne hollow cathode discharge lamp and the fore optics for solar viewing. Not shown is an additional mirror which directs the lamp light to the solar diffuser plate for diffuser reflectivity monitoring.

Figure 2. *GOME Solar Spectrum from July 22, 1995.* Principal solar absorption features, including the MgII doublet (289nm) and the CaII K line (394nm), are identified. Asterisks mark instrumental artifacts due to the changing transmission characteristics of the anti-reflection coating on the channel 3 beam splitter (450nm) and due to a Wood anomaly in the Channel 4 holographic grating (700nm). The overlap regions between the four optical GOME channels are at 315nm, 405nm, and 600nm.

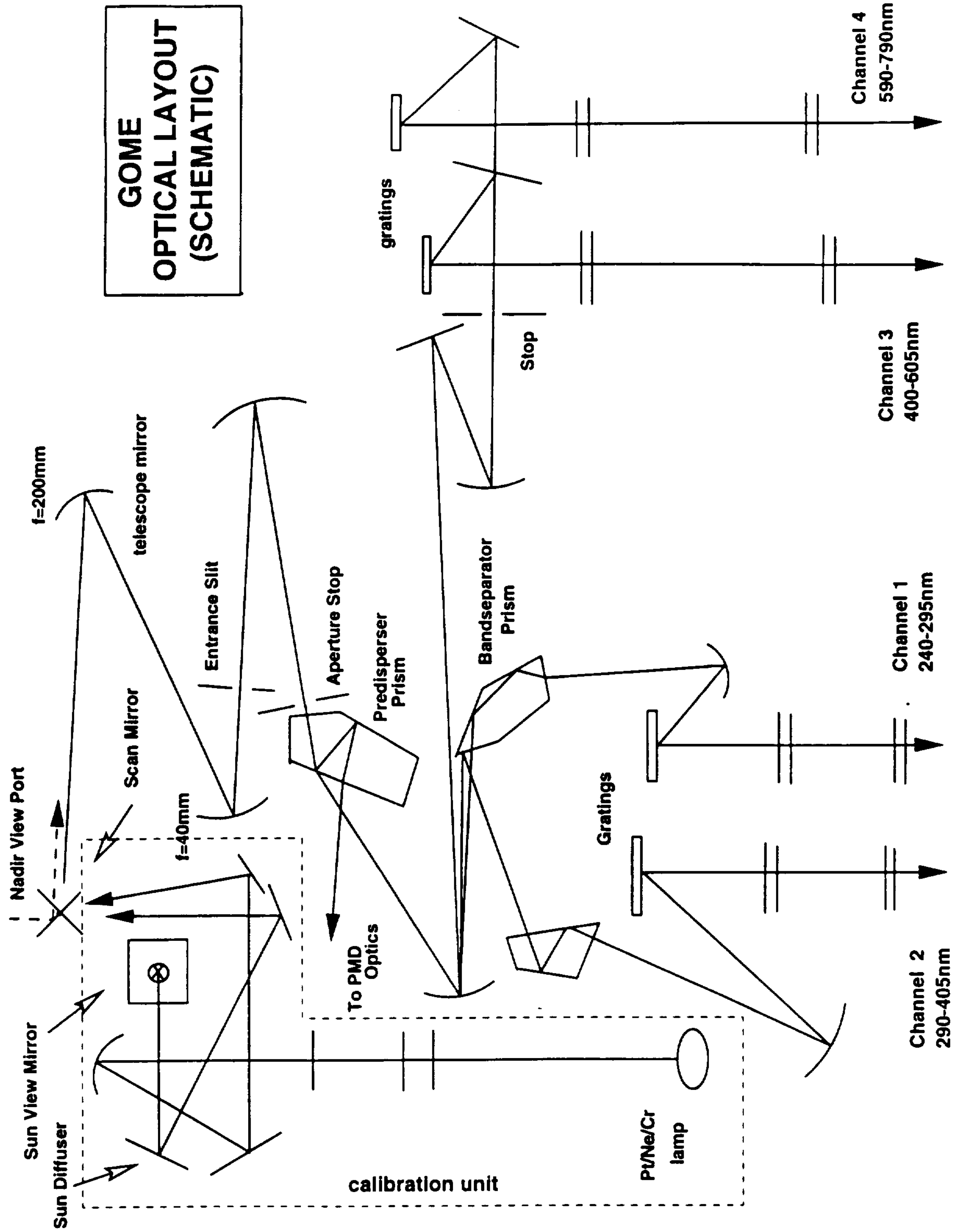
Figure 3. *Comparison of the SSBUV-8 and GOME irradiance values (Burrows et al.* 1997).

Figure 4. *The MgII doublet at 280nm as observed by GOME.* All 221 spectra used in the time series analysis (June 28, 1996–March 31, 1997) have been plotted on top of each other. The chromospheric emission in the core region of the MgII doublet is indicated by three adjacent solid points for each peak. The bottom curve shows the residuals of each of the daily solar spectra relative to the GOME spectrum recorded on January 14, 1997, multiplied by a factor of ten. The variability of the chromospheric emission can be easily recognized in the residual plot. Six wavelengths in the core region of the MgII doublet are averaged to obtain the core value of the MgII index. Four points in the wing, which are

the maxima of parabolas fitted in the windows, 275.8–276.3nm, 276.3–276.8nm, 283.9–283.3nm, and 283.7–284.1nm, are used to calculate the wing value. The mean of the four wing values is indicated by the dashed line. The solar activity index is given by the ratio of the mean core values over the mean wing values. The GOME absolute solar irradiance have been corrected for UV degradation with time and the observed etalon effect.

Figure 5. *GOME MgII Index Times Series from June 28, 1996 until March 31, 1997.* The points are the daily GOME index values as defined in Fig. 4 and the solid line is the SUSIM V19r2 MgII index, which has been scaled to the GOME index value range by linear regression (see text). From the linear regression a correlation coefficient of $r = 0.924$ between the two time series was determined.

Figure 6. *Daily peak irradiance value of CaII K at 393.5nm (top panel) and MgII at 279.5nm (middle) and at 280.5nm (bottom) during the period June 28, 1996–March 31, 1997.* From the MgII peak irradiances the MgII proxy solar activity index (see Figure 4 and 5) were derived. The modulation of the peak irradiances of all three solar Fraunhofer lines are related to chromospheric emission originating from plage areas moving in and out the field of view of the instrument in the course of the 28-day rotation of the sun.



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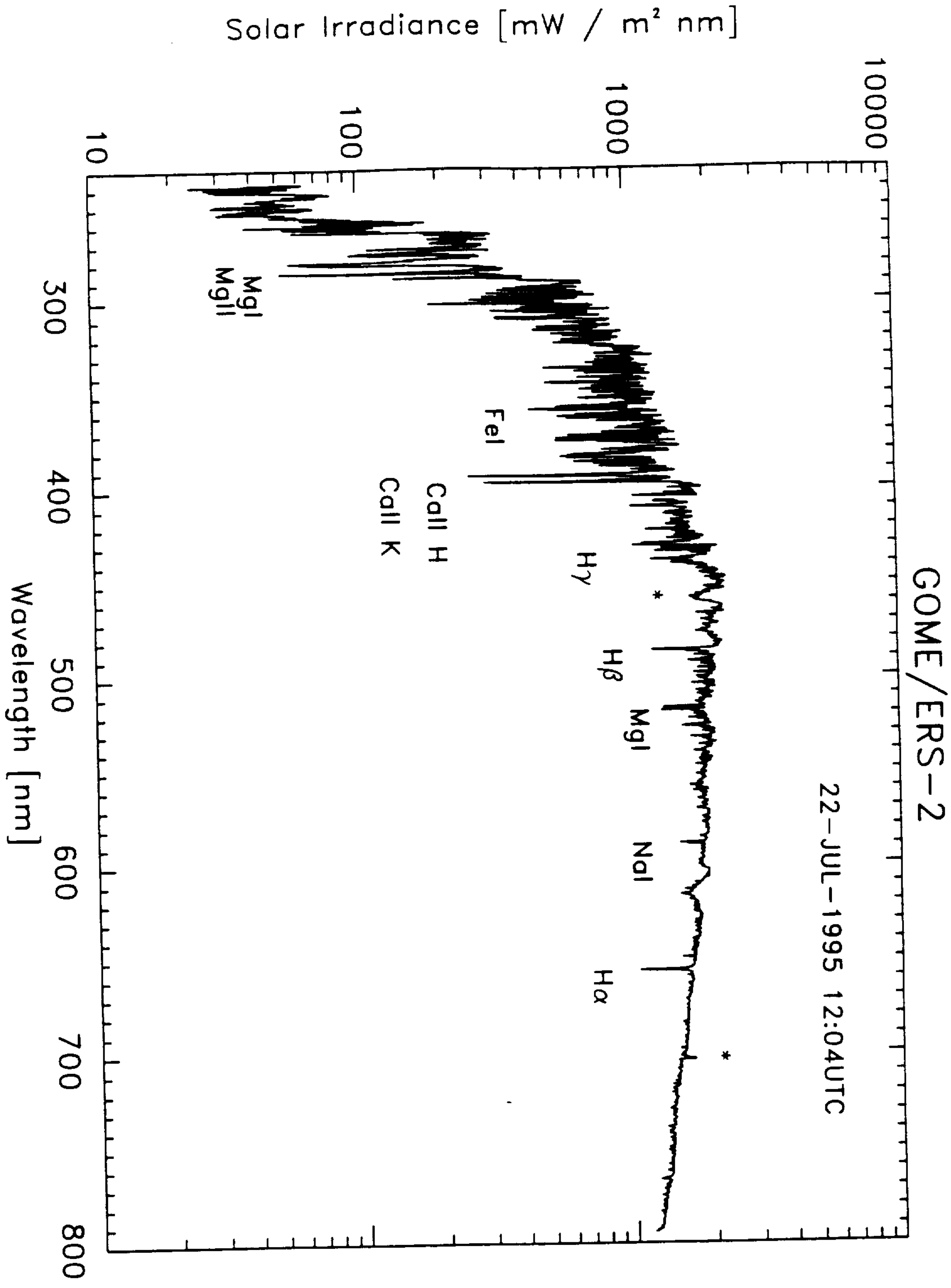

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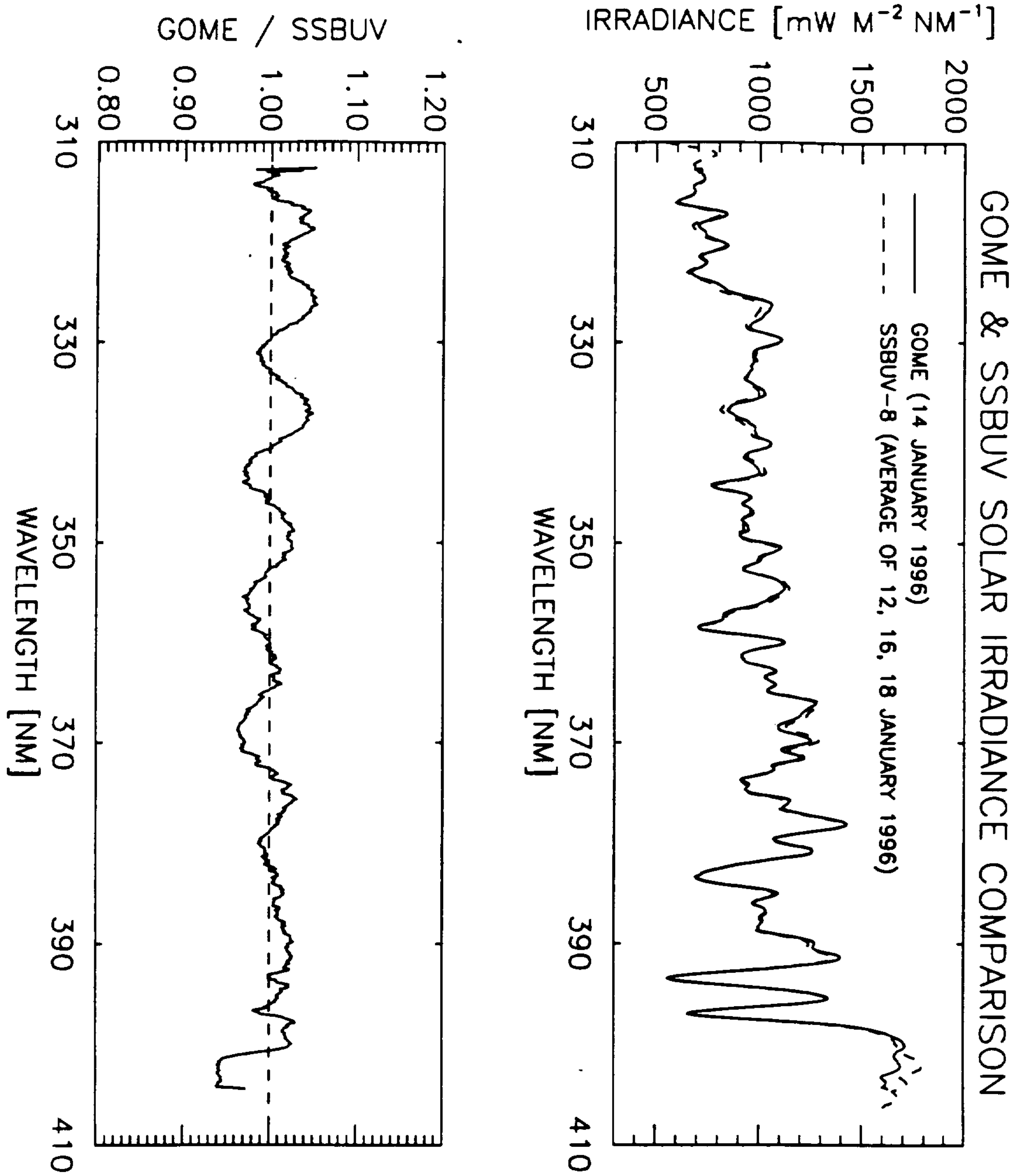

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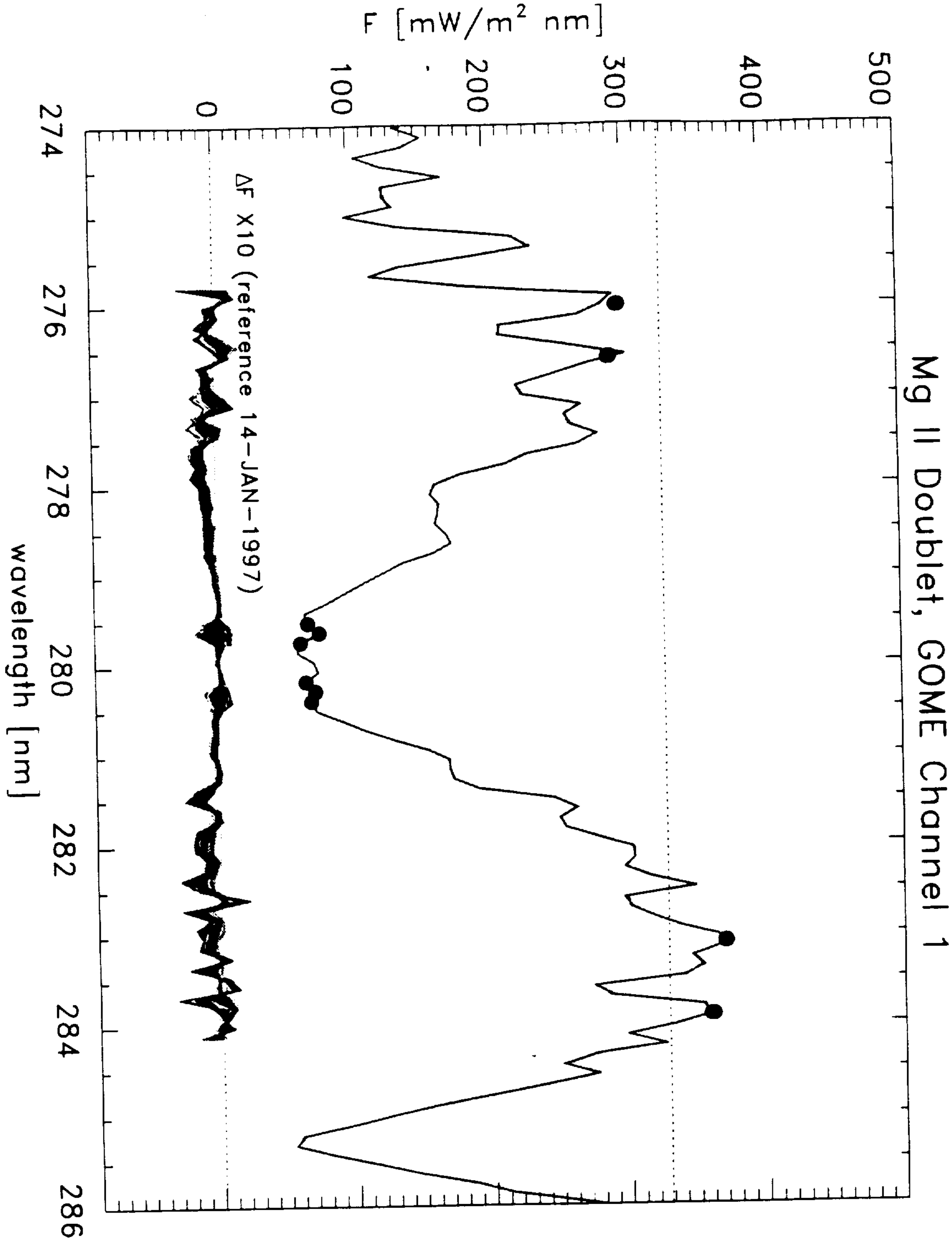
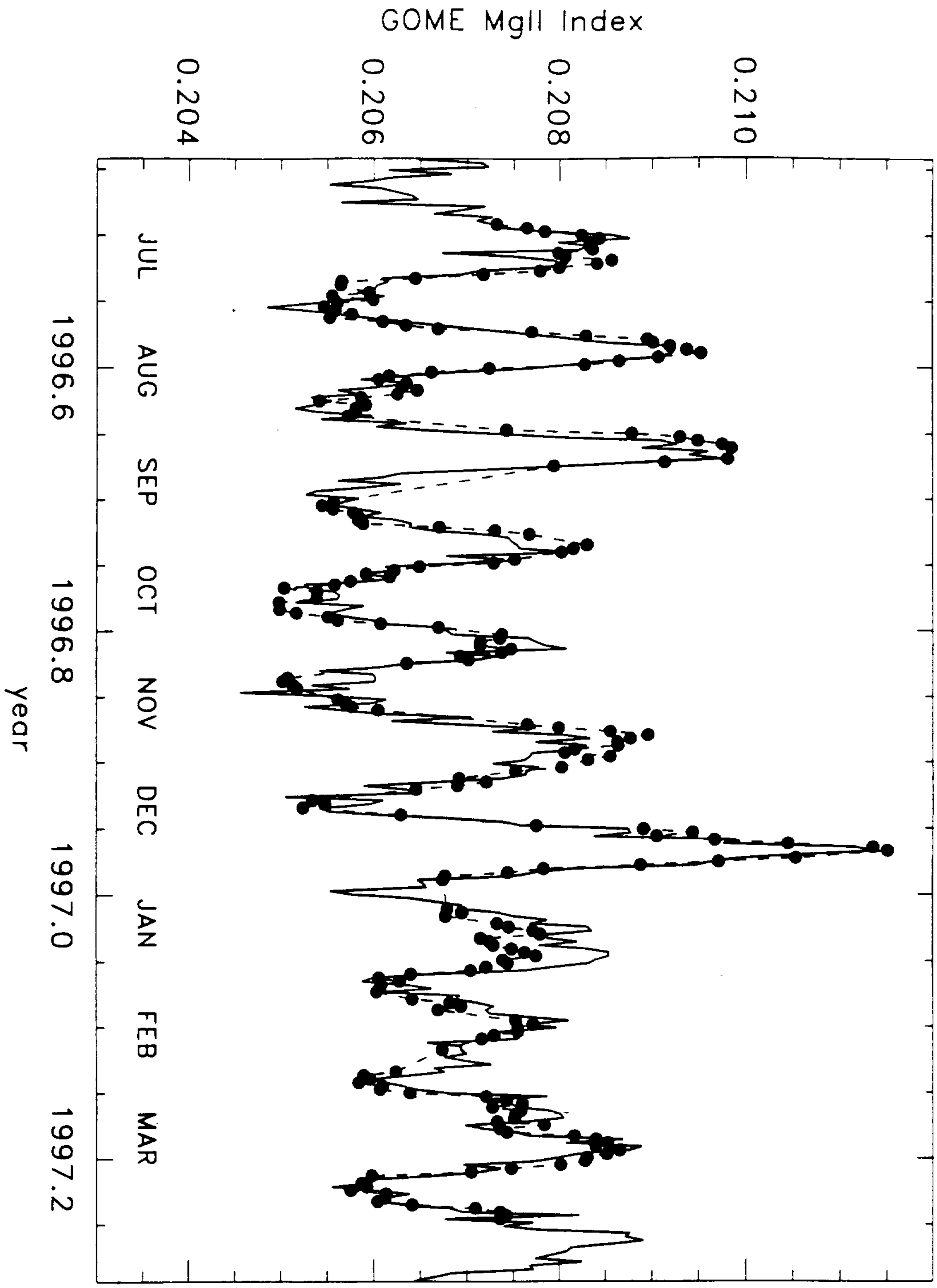


Figure 4: idl0_paper_a.ps



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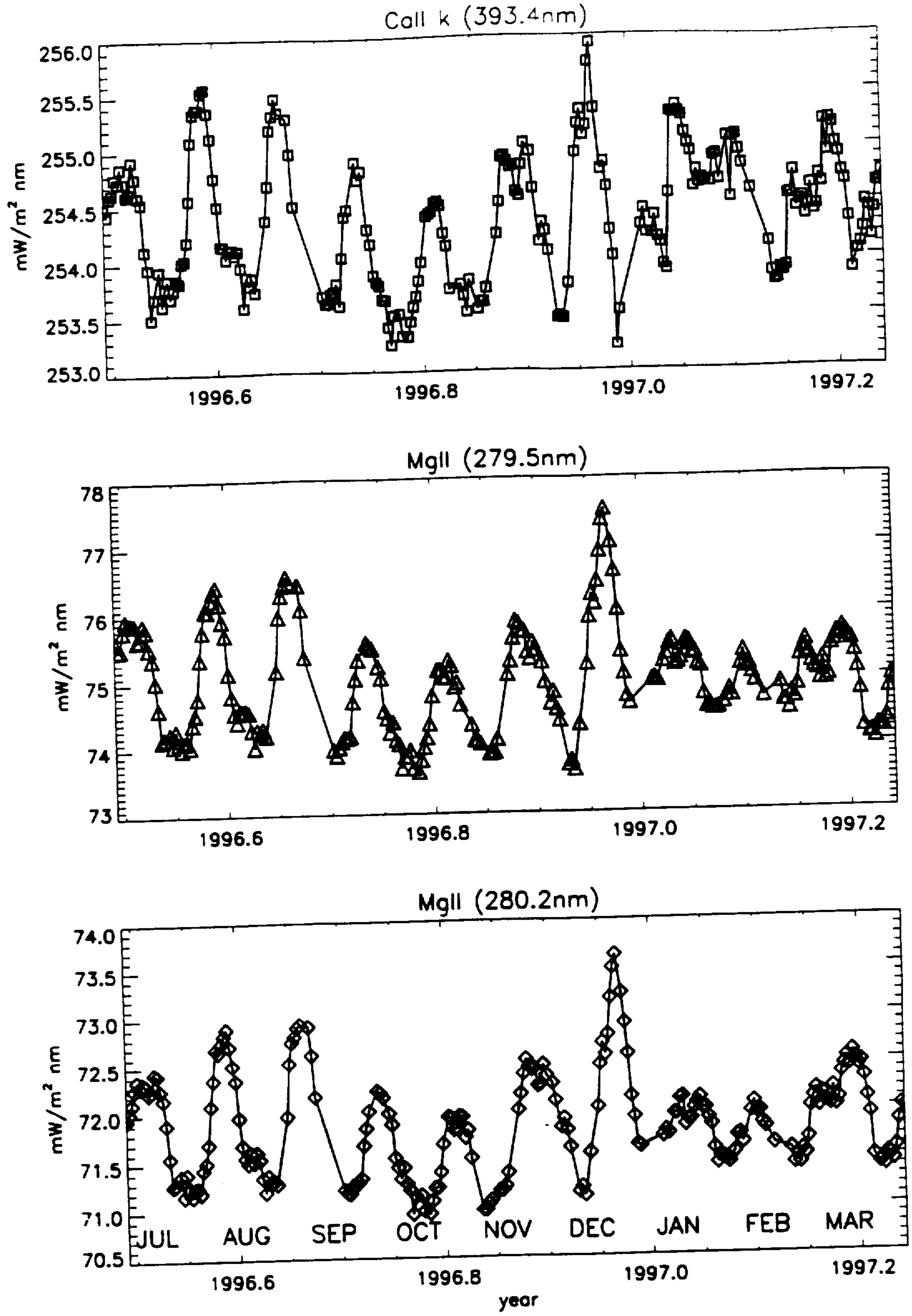

Figure 6: pk_irr.ps